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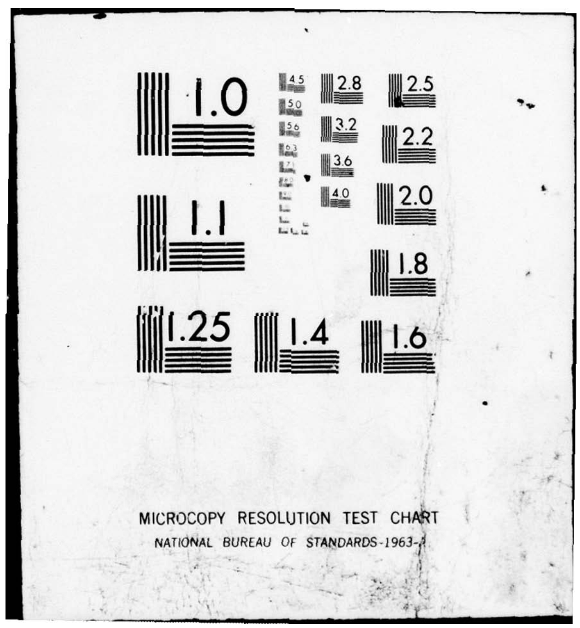
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TECHNICAL REPORT
HMS-R02-78

LEVEL II

HELICOPTER FLIGHT AND LABORATORY VIBRATION TESTS FOR FLIGHT DEMONSTRATION MODEL OF AIRSPRING VIBRATION ISOLATOR

PREPARED UNDER
CONTRACT NUMBER: DAAK40-77-C-0121
FOR
GROUND EQUIPMENT AND MISSILE STRUCTURE DIRECTORATE
TECHNOLOGY LABORATORY
U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND
REDSTONE ARSENAL, ALABAMA 35809

30 JANUARY 1978

HUNTSVILLE ELECTRONICS DIVISION CHRYSLER CORPORATION

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TECHNICAL REPORT HMS-R02-78

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HELICOPTER FLIGHT
AND
LABORATORY VIBRATION TESTS
FOR
FLIGHT DEMONSTRATION MODEL
OF
AIRSPRING VIBRATION ISOLATOR

By

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Prepared Under

Contract Number: DAAK40-77-C-0121 15

For

Ground Equipment and Missile Structure Directorate

Technology Laboratory

U. S. Army Missile Research and Development Command

Redstone Arsenal, Alabama 35809

12 112p.

11 30 January 1978

Chrysler Corporation

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I. INTRODUCTION

It has been reported that the vibrations induced by the rotor of the helicopter affect the performance of the missile guidance system. As an approach to alleviate the problem, an isolation system designated as Airspring Vibration Isolator (AVI) was developed to isolate the rotor-induced vibration from transmitting to the launcher-missile system. Based on the concept developed in reference 1, a ground demonstration model of the AVI was designed and manufactured at MIRADCOM. Under contract DAAH01-76-C-0686, Chrysler designed and manufactured a flight demonstration model of the AVI. The design and manufacture of the AVI flight demonstration model was to follow the concept of the AVI ground demonstration model with improvement in performance and reduction in weight. Under this contract Chrysler is to assist MIRADCOM to conduct laboratory vibration tests and helicopter flight tests of the AVI flight demonstration model. Chrysler's responsibility includes the preparation of test plans, the monitoring of tests and the evaluation of test results.

The laboratory vibration tests of the AVI flight demonstration model include a vertical vibration test, transverse vibration test and longitudinal vibration test with base excitations along the three principal axes, respectively. Each vibration test in turn includes a sweep-sine test, random test and shock test. Laboratory longitudinal vibration test was performed on 6 and 7 July 1977, transverse vibration test on 7 and 8 September 1977, and vertical vibration test on 16 and 17 October 1977. Test results of the laboratory vertical vibration test are documented in reference 2, those of the transverse vibration test in reference 3, and

those of the longitudinal vibration test in reference 4. In addition to the test results, test plans and analyses are also included in these documents.

In the laboratory vertical vibration test the same launcher-missile system was tested with and without the AVI to investigate the vibration performance of the AVI. It was found that the vibration levels of the launcher-missile system with the AVI installed were significantly less than without the AVI. This is an indication that the AVI is good in isolating vertical vibrations.

The Helicopter flight test of the AVI was performed on 4 January 1978. The flight profile included take-off, hovering, 30 and 60 knot level flights, and landing. Flight test results are documented in reference 5. The isolation performance of the AVI during the helicopter flight was found to be good in general.

In order to accurately determine the vibration isolation performance of the AVI during the helicopter flight, vibration data for the same launcher-missile system without the AVI under the same flight conditions are required to compare with those obtained with the AVI installed. Since helicopter flight test of the launcher-missile system without the AVI is not included in the schedule of this contract, it is recommended the helicopter flight test of the launcher-missile system without the AVI be performed.

II. HELICOPTER FLIGHT TEST AND LABORATORY VIBRATION TESTS

2.1 HELICOPTER FLIGHT TEST

The helicopter flight test of the flight demonstration model of the Airspring Vibration Isolator was performed on Wednesday morning, of 4 January 1978 in Redstone Arsenal, Alabama. The total flight time was 35 minutes The weather was clear and cold at 36°F, and the wind was less than ten miles per hour. In addition to acceleration measurements, movie camera coverage was also obtained. Because of the limited available number of channels of the Government furnished tape recorder, only nine acceleration measurements were taken: three acceleration measurements along the longitudinal, transverse, and vertical axes were obtained at the AVI-upper-plate-center. Two acceleration measurements were obtained along the transverse and the vertical axes at the launcher-front-end, the launcher-rear-end, and the AVI-lower-plate-center, respectively. Data reduction was performed in MIRADCOM to obtain response power spectral density plots in both acceleration and displacement units. The results show that the AVI is good in isolating acceleration vibrations encountered in the flight. Since the same launcher-missile system without the AVI was not flown in this flight test, vibration data of the launcher-missile system without the AVI were not available for comparison with those with the AVI. In order to determine accurately the vibration isolation performance of the AVI, it is recommended that helicopter flight tests of the same launcher-missile system without the AVI be performed. Results of the helicopter flight test of the AVI are given in reference 5.

2.1.1 HELICOPTER FLIGHT TEST PLANT

"Helicopter Flight Test Plan for Flight Demonstration Model of Airspring Vibration Isolator," Chrysler Technical report HSM-06-77, (see reference 6), was published on 31 August 1977 and submitted to MIRADCOM for approval. The flight test plant describes the test objectives, the test configuration, the flight profile, instrumentation requirements, data reduction requirements, center-of-gravity and mass movement of inertia data, AVI design loads and factor of safety, the compressed nitrogen gas supply system, electrical power requirements for the flight test, and analyses of possible failure modes.

2.1.2 FLIGHT TEST CONFIGURATION

The AVI-Launcher-Missile system was installed under the outboard pylon of the AH-1 helicopter left-stub-wing, and the compressed-nitrogen-supply system was installed under the inboard pylon of the left-stub-wing as shown in Figure 2-1. The AVI-launcher-missile system has a total weight of 300 pounds as shown in Figure 2-2. The compressed-nitrogen-supply cylinder was strapped to a Hellfire single-rail launcher to facilitate its installation under the pylon as shown in Figure 2-3, and this launcher-cylinder system has a total weight of 114 pounds. To balance the loads on the helicopter left-stub-wing, a M-200 launcher with one 2.75-inch dummy rocket in the center (total weight 161 pounds) was installed under the outboard pylon of the helicopter right-stub-wing, and a single-rail Hellfire launcher with a dummy Hellfire missile (total weight 137 pounds) was installed under the inboard pylon of the right-stub-wing.

The nitrogen pressure inside the compressed nitrogen supply cylinder was 1750 psig before the helicopter took off. The pressure regulator in the

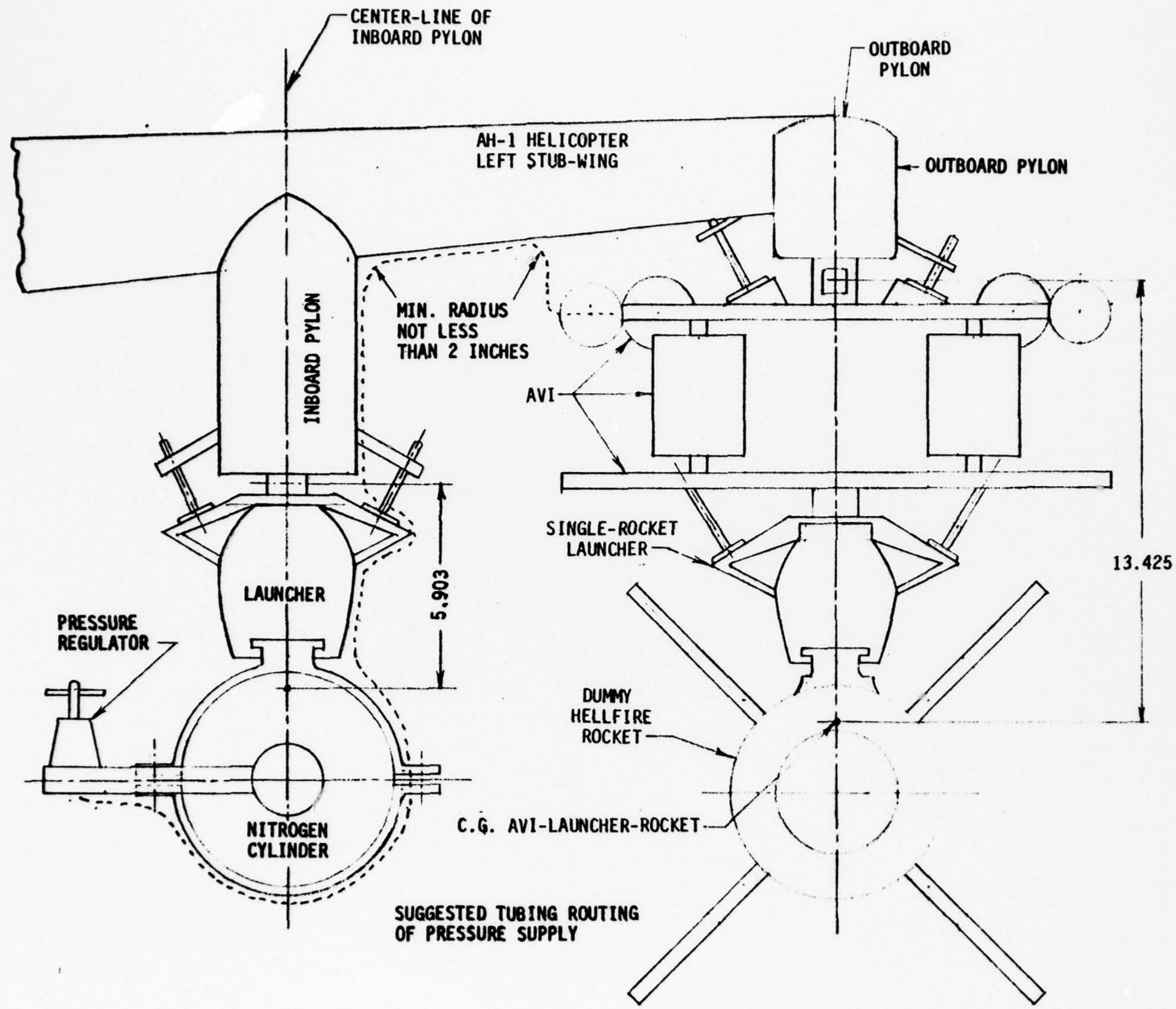

FIGURE 2-1 AVI-LAUNCHER-MISSILE AND COMPRESSED-NITROGEN-SUPPLY SYSTEMS MOUNTED UNDER LEFT-STUB-WING OF AH-1 HELICOPTER, FRONT VIEW

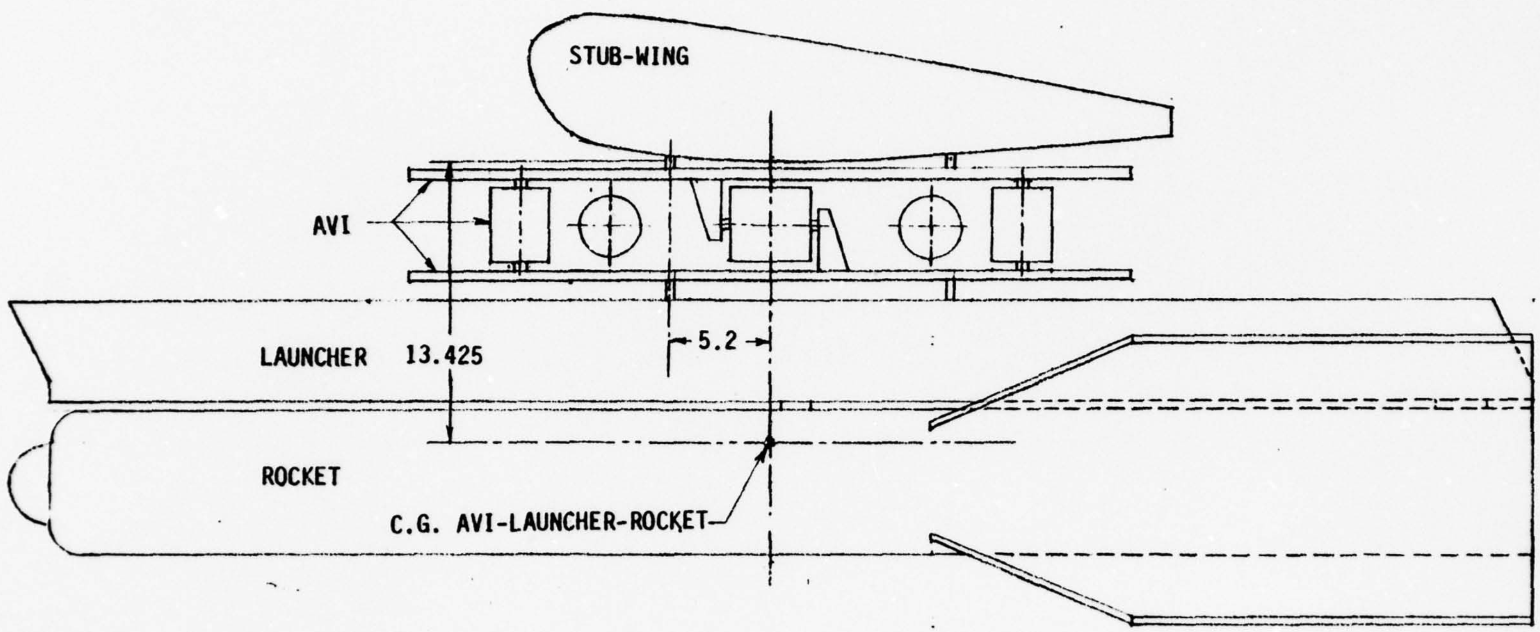

FIGURE 2-2. AVI-LAUNCHER-MISSILE SYSTEM INSTALLED UNDER AH-1 HELICOPTER STUB-WING, LEFT SIDE VIEW

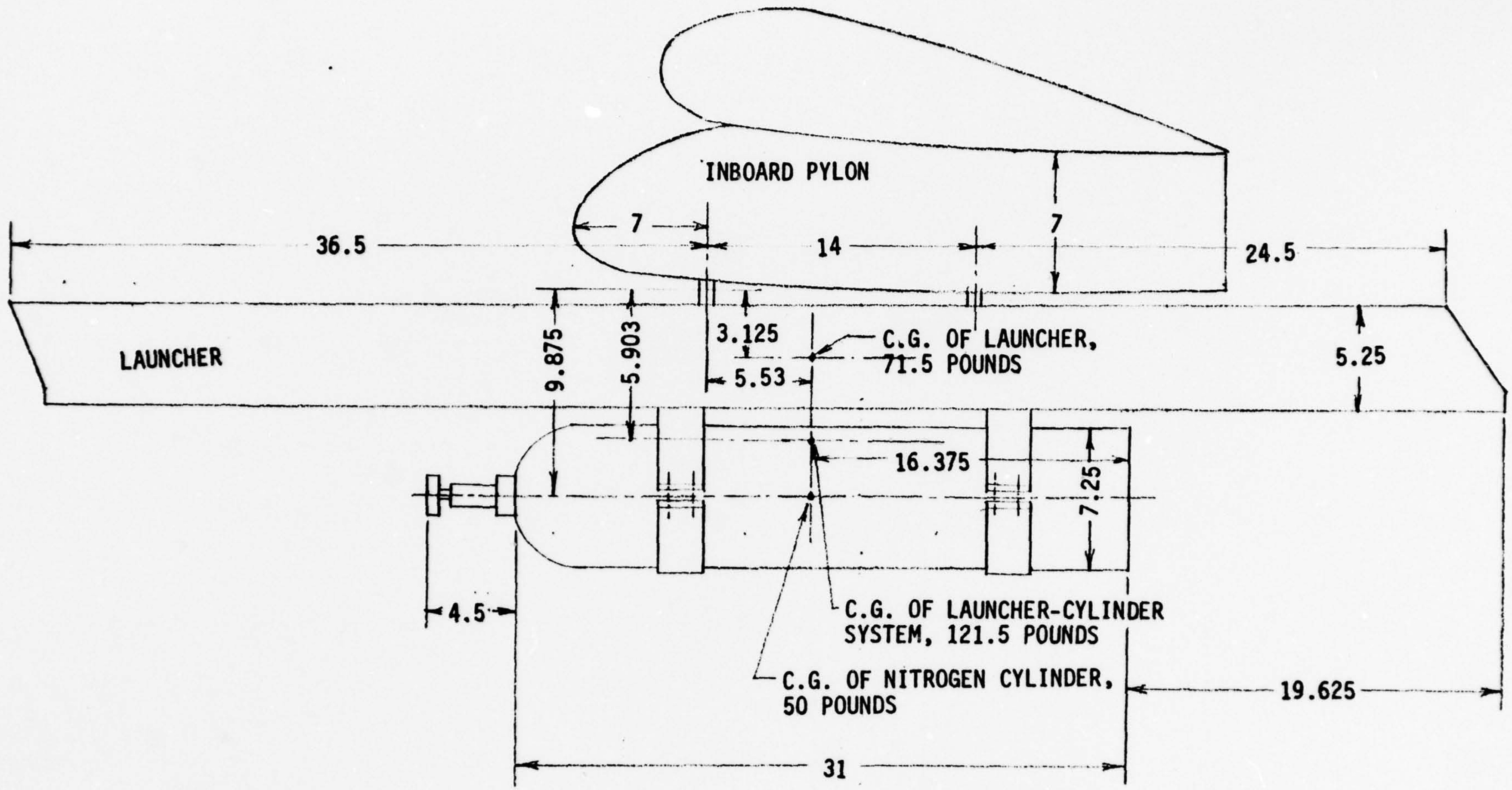

FIGURE 2-3. COMPRESSED-NITROGEN-SUPPLY SYSTEM MOUNTED UNDER INBOARD PYLON OF LEFT-STUB-WING, SIDE VIEW

supply cylinder was adjusted to supply 200 psig nitrogen pressure to the AVI. One pressure regulator in the AVI further reduced the nitrogen pressure to 90 psig for the servo-level pneumatic isolator mounts. Another pressure regulator in the AVI reduced the nitrogen pressure to 100 psig for the AVI pneumatic locking system. The preload pressure on the two transverse isolator mounts was adjusted to 25 psig. Since the Government furnished longitudinal servo-level isolator mount was leaking, a rigid link was installed as a substitute for the longitudinal isolator mount.

2.1.3 INSTRUMENTATIONS AND DATA RECORDING

Since only nine channels of the Government furnished tape recorder were available for instrumentation measurements, nine acceleration measurements were taken during the flight test: two acceleration measurements were obtained along the transverse and the vertical axes at the launcher-front-end, the launcher-rear-end, and the AVI-lower-plate-center, respectively. Three acceleration measurements were obtained along the longitudinal, the transverse, and the vertical axes at the AVI-upper-plate-center. The tape recorder and associated equipment package, having a total weight of 183 pounds, 40 inches in overall length, and 25 inches in overall width, was installed in the helicopter ammunition bay. The cables, running from the instrumentation-package to the accelerometers and having a total weight of 5 pounds, were attached and strapped to the helicopter fuselage and wing with anchorage fittings and adhesive tape. Data recording was operated and controlled in the helicopter gunner's compartment. A 16-mm movie camera was mounted on the left-side of the helicopter landing sledge to monitor the movement of the launcher-missile system under the AVI.

2.1.4 FLIGHT PROFILE

The actual flight profile was exactly as the first flight profile in the flight test plan, which is shown in Table 2-1. The AH-1 helicopter took off on the pad near the high-bay hanger of Building 5400 at Redstone Arsenal. After hovering at 20 feet above ground, the helicopter lifted off to about three hundred feet above the ground to make the 30 and 60 knot level flights in a left-turn (counterclockwise) circle of approximately one mile radius.

2.2 LABORATORY VERTICAL VIBRATION TESTS

The laboratory vertical vibration tests of the helicopter flight demonstration model of the Airspring Vibration Isolator (AVI) were performed on 14 and 17 October 1977 in the dynamic test laboratory of MIRADCOM. The low frequency electro-hydraulic shaker was used to perform the tests. The vertical vibration tests included sweep-sine tests, random excitation tests and shock tests. In addition, vertical vibration tests of the launcher-missile system without the AVI were also performed. A total of 12 sweep-sine test runs, eight random test runs, and six half-sine shock test runs were performed in the laboratory vertical vibration tests. Identification and description of the vertical vibration test runs are given in Section 3.1. Detailed test results of the vertical vibration tests were documented in Reference 2.

TABLE 2-1. FLIGHT PROFILE

SEQUENCE AND FLIGHT CONDITION DESIGNATION NUMBER	DESCRIPTION	MINIMUM DATA RECORDING TIME DURATION (MINUTES)
1	Take-off with locking system on, 100 psig pressure	As permitted
2	Twenty feet above ground hovering with locking system on, 100 psig pressure	2
3	Twenty feet above ground hovering with locking system off	2
4	30 Knot level flight with locking system off	2
5	60 knot level flight with locking system off	2
6	60 knot level flight with locking system on, 100 psig pressure	2
7	Landing for changing locking system pressure to 5 psig	As permitted
8	Take-off, locking system on, 5 psig pressure	As permitted
9	Twenty feet above ground with locking on, 5 psig pressure	2
10	60 knot level flight with locking system on, 5 psig pressure	2
11	Landing	As permitted

2.3 LABORATORY TRANSVERSE VIBRATION TESTS

The laboratory transverse vibration test of the flight demonstration model of the Airspring Vibration Isolator was performed on 7 and 8 September 1977 in the Dynamic Test Laboratory of MIRADCOM. The vibration shaker used is the MIRADCOM hydraulic low frequency shaker. The transverse vibration test included sweep frequency sinusoidal test, random excitation tests and shock tests. A total of ten sweep-sine test runs, eight random test runs and four half-sine shock test runs were performed in the laboratory transverse vibration tests. Identification and description of the transverse vibration test runs are given in Section 3.2. Detailed test results of the transverse vibration tests were documented in Reference 3.

2.4 LABORATORY LONGITUDINAL VIBRATION TESTS

The laboratory longitudinal vibration test of the flight demonstration model of the Airspring Vibration Isolator was performed on July 6 and 7, 1977, the Dynamic Test Laboratory of MIRADCOM. The MIRADCOM low frequency hydraulic shaker was used to perform the test. The longitudinal vibration test included sweep frequency sinusoidal test, random excitation test, and shock test. A total of 14 sweep-sine test runs, eight random test runs, and four half-since shock test runs were performed in the laboratory longitudinal vibration tests. Identification and description of the longitudinal vibration test runs are given in Section 3.3. Detailed results of the longitudinal vibration tests were documented in Reference 4.

III. IDENTIFICATION OF LABORATORY VIBRATION TESTS

3.1 VERTICAL LABORATORY VIBRATION TESTS

3.1.1 VERTICAL SWEEP-SINE TESTS

The following 12 vertical sweep-sine tests were performed:

3.1.1.1 Sweep-Sine Test 1

AVI unlocked. From 1 to 20 Hertz, constant double-displacement amplitude at 0.1 inch. From 20 to 300 Hertz, constant acceleration at 2 g peak.

3.1.1.2 Sweep-Sine Test 1A

AVI unlocked. From 1 to 6.4 Hertz constant double-displacement amplitude at 0.1 inch. From 6.4 to 200 Hertz constant acceleration peak at 0.2 g.

3.1.1.3 Sweep-Sine Test 2

Same as Test 1 except AVI locked with 100 psig pressure.

3.1.1.4 Sweep-Sine Test 3

Same as Test 1 except AVI locked with 10 psig pressure.

3.1.1.5 Sweep-Sine Test 4

Same as Test 1 except AVI locked with 5 psig pressure.

3.1.1.6 Sweep-Sine Test 5

Same as Test 1 except missile and launcher tied together, AVI locked with 100 psig pressure.

3.1.1.7 Sweep-Sine Test 6

AVI unlocked. Same as Test 1 except missile and launcher tied together.

3.1.1.8 Sweep-Sine Test 7

Same as Test 1 except AVI locked with 40 psig pressure.

3.1.1.9 Sweep-Sine Test 8

Same as Test 1 except AVI locked with 15 psig pressure.

3.1.1.10 Sweep-Sine Test 9

Same as Test 1 except AVI locked with 20 psig pressure.

3.1.1.11 Sweep-Sine Test 10

Same as Test 1 except without AVI.

3.1.1.12 Sweep-Sine Test 10A

Repeat Test 10.

3.1.2 VERTICAL RANDOM TESTS

3.1.2.1 Excitation Spectrum

The minus three decibel level of the excitation spectrum is shown in Figures 4-1 and 4-2.

3.1.2.2 Random Test 1

AVI unlocked. Use -3 decibel level for the excitation spectrum and test for three minutes.

3.1.2.3 Random Test 2

Same as Test 1 except AVI locked with 100 psig pressure.

3.1.2.4 Random Test 3

AVI unlocked. Use zero decibel level of the excitation spectrum and test for three minutes.

3.1.2.5 Random Test 4

Same as Test 3 except AVI locked with 100 psig pressure.

3.1.2.6 Random Test 5

Same as Test 3 except AVI locked with 20 psig pressure.

3.1.2.7 Random Test 6
Same as Test 3 except AVI locked with 10 psig pressure.

3.1.2.8 Random Test 7
Same as Test 1 except without AVI.

3.1.2.9 Random Test 8
Same as Test 3 except without AVI.

3.1.3 VERTICAL SHOCK TESTS

3.1.3.1 Excite the system with a half-sine, 25 ms, 0.5-g peak shock. Run three times. AVI unlocked

3.1.3.2 Same as 1 except AVI locked with 100 psig pressure

3.1.3.3 Excite the system with a half-sine, 25 ms, 1-g peak shock. Run three times. AVI unlocked.

3.1.3.4 Same as 3 except AVI locked with 100 psig pressure.

3.1.3.5 Same as 3.1.3.1 except without AVI.

3.1.3.6 Same as 3.1.3.3 except without AVI.

3.2 LONGITUDINAL LABORATORY VIBRATION TESTS

3.2.1 LONGITUDINAL SWEEP-SINE TESTS
The following 14 longitudinal sweep-sine tests were performed:

3.2.1.1 Sweep-Sine Test 1
AVI unlocked. From 1 to 5 Hertz, constant double-displacement amplitude at 0.08 inch. From 5 to 50 Hertz, constant acceleration at 0.1 g peak.

3.2.1.2 Sweep-Sine Test 2
AVI locked with 200 psig pressure. From 1 to 8 Hertz, constant double-displacement at 0.060 inch. From 8 to 50 Hertz, constant acceleration at 0.2 g peak.

3.2.1.3 Sweep-Sine Test 3

Same as Test 2 except AVI locked with 150 psig pressure.

3.2.1.4 Sweep-Sine Test 4

Same as Test 2 except AVI locked with 100 psig pressure.

3.2.1.5 Sweep-Sine Test 5

Same as Test 1 except AVI locked with 50 psig pressure.

3.2.1.6 Sweep-Sine Test 6

Same as Test 1 except AVI locked with 20 psig pressure.

3.2.1.7 Sweep-Sine Test 7

Same as Test 1 except AVI locked with 15 psig pressure.

3.2.1.8 Sweep-Sine Test 8

Same as Test 1 except AVI locked with 10 psig pressure.

3.2.1.9 Sweep-Sine Test 9

Same as Test 1 except AVI locked with 5 psig pressure.

3.2.1.10 Sweep-Sine Test 10

Same as Test 1 except AVI locked with 2 psig pressure.

3.2.1.11 Sweep-Sine Test 11

Same as Test 1 except missile and launcher tied together, AVI locked with 100 psig pressure, and frequency range up to 100 Hertz.

3.2.1.12 Sweep-Sine Test 11B

Same as Test 11 except locking system is operated several times from 40 Hertz up to test the locking system.

3.2.1.13 Sweep-Sine Test 12

AVI unlocked. Missile and launcher tied together. From 1 to 5 Hertz, constant double-displacement amplitude at 0.08 inch. From 5 to 10 Hertz, constant acceleration at 0.1 g peak. From 10 to 15 Hertz, peak-g manually increased linearly from 0.1 to 0.4 g. From 15 to 50 Hertz, constant acceleration at 0.4 g peak.

3.2.1.14 Sweep-Sine Test 12A

Same as Test 12 except missile and launcher not tied together.

3.2.2 LONGITUDINAL RANDOM TESTS

3.2.2.1 Excitation Spectrum

For convenience of comparison with test results of the AVI ground demonstration model, the -3 decibel level of the excitation spectrum is shown in Figure 4-1. This reference spectrum was used in all random tests of the AVI ground model. However, for this test it is preferred to have the spectrum to extend linearly to the lowest frequency as 0.5 Hertz as the equipment permit.

3.2.2.2 Random Test 1

AVI unlocked. Use -9 decibel level of the excitation spectrum and test for 5 minutes.

3.2.2.3 Random Test 2

Same as Test 1 except AVI locked with 100 psig pressure.

3.2.2.4 Random Test 3

AVI locked. Use -6 decibel level of the excitation spectrum and test for 5 minutes.

3.2.2.5 Random Test 4

Same as Test 3 except AVI locked with 100 psig pressure.

3.2.2.6 Random Test 5

Same as Test 3 except AVI locked with 2 psig pressure.

3.2.2.7 Random Test 6

Same as Test 3 except AVI locked with 5 psig pressure.

The following random tests are to determine the dynamic effect of the clearance between the launcher guide-rail and the missile. For these two tests, the accelerometer on the launcher-front-end is moved backward 2.5 inches, making it 37.5 inches from the missile-front-lug, and the

accelerometer originally on the launcher-rear-end is moved to the bottom of the missile-front-end directly under the accelerometer on the launcher-front-end.

3.2.2.8 Random Test 7

AVI unlocked. Use -6 decibel level of the excitation spectrum and test for 5 minutes.

3.2.2.9 Random Test 8

Same as Test 7 except AVI is locked with 100 psig pressure.

3.2.3 LONGITUDINAL SHOCK TESTS

3.2.3.1 Excite the system with a half-sine, 25 ms, 0.5-g peak shock. Run three times. AVI unlocked.

3.2.3.2 Same as 3.2.3.1 except AVI locked with 100 psig pressure.

3.2.3.3 Excite the system with a half-sine, 25 ms, 1-g peak shock. Run three times. AVI unlocked.

3.2.3.4 Same as 3.2.3.3 except AVI locked with 100 psig pressure.

3.3 TRANSVERSE LABORATORY VIBRATION TESTS

3.3.1 TRANSVERSE SWEEP-SINE TESTS

The following ten transverse sweep-sine tests were performed:

3.3.1.1 Sweep-Sine Test 1

AVI unlocked. From 1 to 7 Hertz, constant double-displacement amplitude at 0.08 inches. From 7 to 18 Hertz, constant acceleration at 0.2 g peak. From 18 to 40 Hertz, constant double-displacement amplitude at 0.012 inches. From 40 to 100 Hertz, constant acceleration at 1 g peak.

3.3.1.2 Sweep-Sine Test 1A

Test 1A is a repeated test of Test 1.

3.3.1.3 Sweep-Sine Test 2

Same as Test 1 except AVI locked with 100 psig pressure.

3.3.1.4 Sweep-Sine Test 2A

From 1 to 7 Hertz, constant double-displacement amplitude at 0.08 inch. From 7 to 18 Hertz, constant acceleration of 0.2 peak. From 28 to 40 Hertz, constant double-displacement amplitude at 0.012 inch. From 40 to 200 Hertz, constant acceleration at 1 g peak, AVI locked with 100 psig pressure.

3.3.1.5 Sweep-Sine Test 3

Same as Test 2A except AVI locked with 10 psig pressure.

3.3.1.6 Sweep-Sine Test 4

Same as Test 2A except AVI locked with 5 psig pressure.

3.3.1.7 Sweep-Sine Test 5

Same as Test 2A except AVI locked with 2 psig pressure.

3.3.1.8 Sweep-Sine Test 6

Same as Test 2A except missile and launcher tied together, AVI locked with 100 psig pressure.

3.3.1.9 Sweep-Sine Test 7

Same as Test 2A except locking system is operated several times from 40 Hertz up to test the locking system.

3.3.1.10 Sweep-Sine Test 8

AVI unlocked. Same as Test 2A except missile and launcher tied together.

3.3.2 TRANSVERSE RANDOM TESTS

3.3.2.1 Excitation Spectrum

For convenience of comparison with test results of the AVI ground demonstration model, the -3 decibel level of the excitation spectrum is as in Figure 4-1. Similar spectra were used in all random tests of the AVI ground model. This spectrum extends linearly to 0.5 Hertz and constant-level to 100 Hertz.

3.3.2.2 Random Test 1

AVI unlocked. Use -9 decibel level of the excitation spectrum and test for 4 minutes.

3.3.2.3 Random Test 2

Same as Test 1 except AVI locked with 100 psig pressure.

3.3.2.4 Random Test 3

AVI unlocked. Use -6 decibel level of the excitation spectrum and test for 4 minutes.

3.3.2.5 Random Test 4

Same as Test 3 except AVI locked with 100 psig pressure.

3.3.2.6 Random Test 5

Same as Test 3 except AVI locked with 2 psig pressure.

3.3.2.7 Random Test 6

Same as Test 3 except AVI locked with 5 psig pressure.

3.3.2.8 Changing Locations of Accelerometers

The following two random tests are to determine the dynamic effect of the clearance between the launcher guide-rail and the missile. For these two tests, the accelerometer on the launcher front-end is moved backward 2.5 inches, making it 37.5 inches from the missile-front-shoe, and the accelerometer originally on the luancher-rear-end is moved to the bottom of the missile-front-end directly under the accelerometer on the launcher-front-end.

3.3.2.9 Random Test 7

AVI unlocked. Use -6 decibel level of the excitation spectrum and test for 4 minutes.

3.3.2.10 Random Test 8

Same as Test 7 except AVI is locked with 100 psig pressure.

3.3.3 TRANSFERSE SHOCK TESTS

3.3.3.1 Excite the system with a half-sine, 25 ms, 0.5 g peak shock. Run three times. AVI unlocked.

3.3.3.2 Same as 1 except AVI locked with 100 psig pressure.

3.3.3.3 Excite the system with a half-sine, 25 ms, 1 g peak shock. Run three times. AVI unlocked.

3.3.3.4 Same as 3 except AVI locked with 100 psig pressure.

IV. ANALYSES OF TEST RESULTS

4.1 DEFINITION OF AVI ISOLATION PERFORMANCE

In the evaluation and analyses of the AVI flight and laboratory vibration tests data, a definition for the AVI isolation performance should be clearly defined. A rigid body as the AVI-launcher-missile system has six degrees of freedom of motion in general: three translations and three rotations along and about any three orthogonal axes. If the excitation force does not pass through the center-of-gravity of the system as in the AVI helicopter flight and laboratory vibration tests, motions of more than one degree of freedom will be excited. In such cases, the response excitation transmissibility is not a good quantity to measure the vibration isolation performance of the isolation system. A logical quantity to measure the vibration isolation performance of systems as the AVI is the ratio of the vibration level without the AVI minus that with the AVI divided by the original level without the AVI. This is the reduction of vibration level with the AVI as compared to without the AVI. The vibration level can be acceleration, velocity, or displacement amplitude when the vibration is sinusoidal. When the vibration is random covering a certain range of frequencies, the vibration level should be power spectral density at specific frequency or composite root-mean-square value of the spectrum in acceleration, velocity or displacement unit. In some of the cases, it may be convenient to use a normalized value of the vibration level, for example transmissibilities or transfer functions. The quantity defined above to measure the AVI isolation performance is a fraction number. The percentage of isolation performance will be 100 times the fraction number. When the vibration is

pure sinusoidal, the isolation performances calculated from levels in acceleration, velocity and displacement units are identical. However, when the vibration is random covering a certain range of frequencies, the isolation performances calculated from levels in acceleration, velocity and displacement units may be different.

4.2 COMPARISON OF RESPONSES OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI, VERTICAL RANDOM TESTS 1 AND 7, 3 AND 8

The base excitation spectra for vertical random tests 1 and 7 are shown in Figures 4-1 and 4-2, respectively. It is seen that these two excitation spectra are almost identical. Vertical random test 1 was performed with the launcher-missile system installed under the AVI, while random test 7 was performed with the same launcher-missile system without the AVI. Three acceleration measurements were obtained for both tests 1 and 7 at the same locations of the launcher-missile system. Similar conditions hold for vertical random tests 3 and 8 as for random test 1 and 7. Thus the comparison of the responses of the launcher-missile system at these three locations is a good measurement of the isolation performance of the AVI.

Acceleration response psd plots at these locations for random tests 1 and 7 are shown in Figures 4.3 through 4.8. It is seen that the response power spectral density without the AVI is significantly larger than with the AVI. Table 4-1 shows the comparison of the response power spectral densities with and without the AVI at two critical frequencies, 11 and 22 Hertz. It is seen that the psd without the AVI is 142.9 to 565 times as large as with the AVI and the percentage of isolation is from 99.3 to 99.8. Table 4-2 shows the comparison of the acceleration response composite rms values of the launcher-missile system with and without the AVI for random tests 1 and 7 and table 4-3 shows the same comparison for random tests 3 and 8. It is seen that the rms value without the AVI is also significantly larger than with the AVI and the percentage of vibration isolation is 77.8 to 90.9 for tests 1 and 7, and 88.4 to 90.7 for tests 3 and 8.

The excitation spectrum for random tests 3 and 8 was taken from Figure 14, page 25 of reference 8. This is the measured vibration data on the front-end of a XM-200 launcher mounted on the inboard pylon of the stub-wing of the AH-1 helicopter, and reprents a level above the average of the actual vibration environments. The excitation spectrum for tests 3 and 8 is three decibels higher than that for tests 1 and 7. Thus the AVI performance of vibration isolation is good for both high and low level excitations.

TABLE 4-1. COMPARISON OF RESPONSE POWER SPECTRAL DENSITIES (G^2/Hz) AT CRITICAL FREQUENCIES, VERTICAL RANDOM TESTS 1 AND 7

RESPONSE AND FREQUENCY	RESPONSE PSD WITH AVI (A)	RESPONSE PSD WITHOUT AVI (B)	RADIO OF PSD WITHOUT TO WITH AVI (B/A)	PERCENTAGE OF VIBRATION ISOLATION 100(1-A/B)
MISSILE-BOTTOM-CENTER VERTICAL RESPONSE AT 11 HERTZ	0.00021	0.061	290.5	99.7
MISSILE-BOTTOM-CENTER VERTICAL RESPONSE AT 22 HERTZ	0.000065	0.012	184.6	99.5
LAUNCHER-FRONT-END VERTICAL RESPONSE AT 11 HERTZ	0.0002	0.060	300	99.7
LAUNCHER-FRONT-END VERTICAL RESPONSE AT 22 HERTZ	0.000017	0.0077	452.9	99.8
LAUNCHER-REAR-END VERTICAL RESPONSE RESPONSE AT 11 HERTZ	0.00042	0.06	142.9	99.3
LAUNCHER-REAR-END VERTICAL RESPONSE AT 22 HERTZ	0.000023	0.013	565	99.8

TABLE 4-2. COMPARISON OF RMS ACCELERATION WITH AND WITHOUT AVI, VERTICAL RANDOM TESTS 1 AND 7

DESCRIPTION	COMPOSITE RMS ACCELERATION GRMS		RATIO OF RESPONSE TO EXCITATION		PERCENTAGE OF VIBRATION ISOLATION
	WITH AVI	WITHOUT AVI	WITH AVI (A)	WITHOUT AVI (B)	100(1-A/B)
VERTICAL EXCITATION	0.42	0.42			
MISSILE-BOTTOM-CENTER VERTICAL RESPONSE	0.164	0.74	0.390	1.762	77.8
LAUNCHER-FRONT-END VERTICAL RESPONSE	0.093	1.02	0.221	2.429	90.9
LAUNCHER-REAR-END VERTICAL RESPONSE	0.118	1.03	0.281	2.452	88.5

NOTE: Composite rms values cover a frequency range from 1 to 250 Hertz.

TABLE 4-3. COMPARISON OF RMS ACCELERATION WITH AND WITHOUT AVI, VERTICAL RANDOM TESTS 3 AND 8

DESCRIPTION	COMPOSITE RMS ACCELERATION GRMS		RATIO OF RESPONSE TO EXCITATION		PERCENTAGE OF VIBRATION ISOLATION
	WITH AVI	WITHOUT AVI	WITH AVI (A)	WITHOUT AVI (B)	100(1-A/B)
VERTICAL EXCITATION	0.58	0.63			
MISSILE-BOTTOM-CENTER VERTICAL RESPONSE	0.177	1.65	0.305	2.619	88.4
LAUNCHER-FRONT-END VERTICAL RESPONSE	0.19	2.17	0.328	3.444	90.5
LAUNCHER-REAR-END VERTICAL RESPONSE	0.172	2.01	0.297	3.190	90.7

NOTE: Composite rms values cover a frequency range from 1 to 250 Hertz.

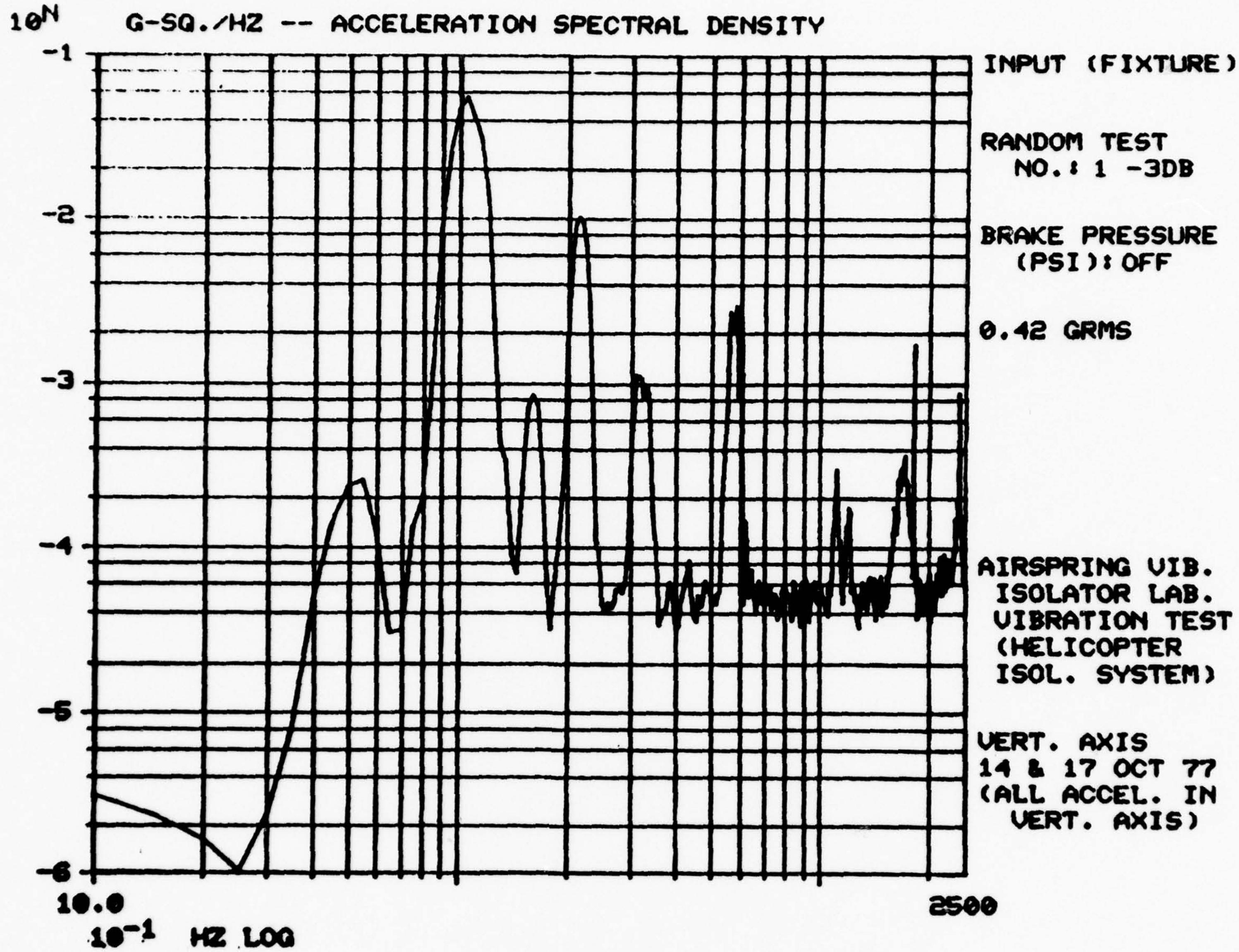

FIGURE 4-1. PSD PLOT OF EXCITATION ACCELERATION SPECTRUM, VERTICAL RANDOM TEST 1

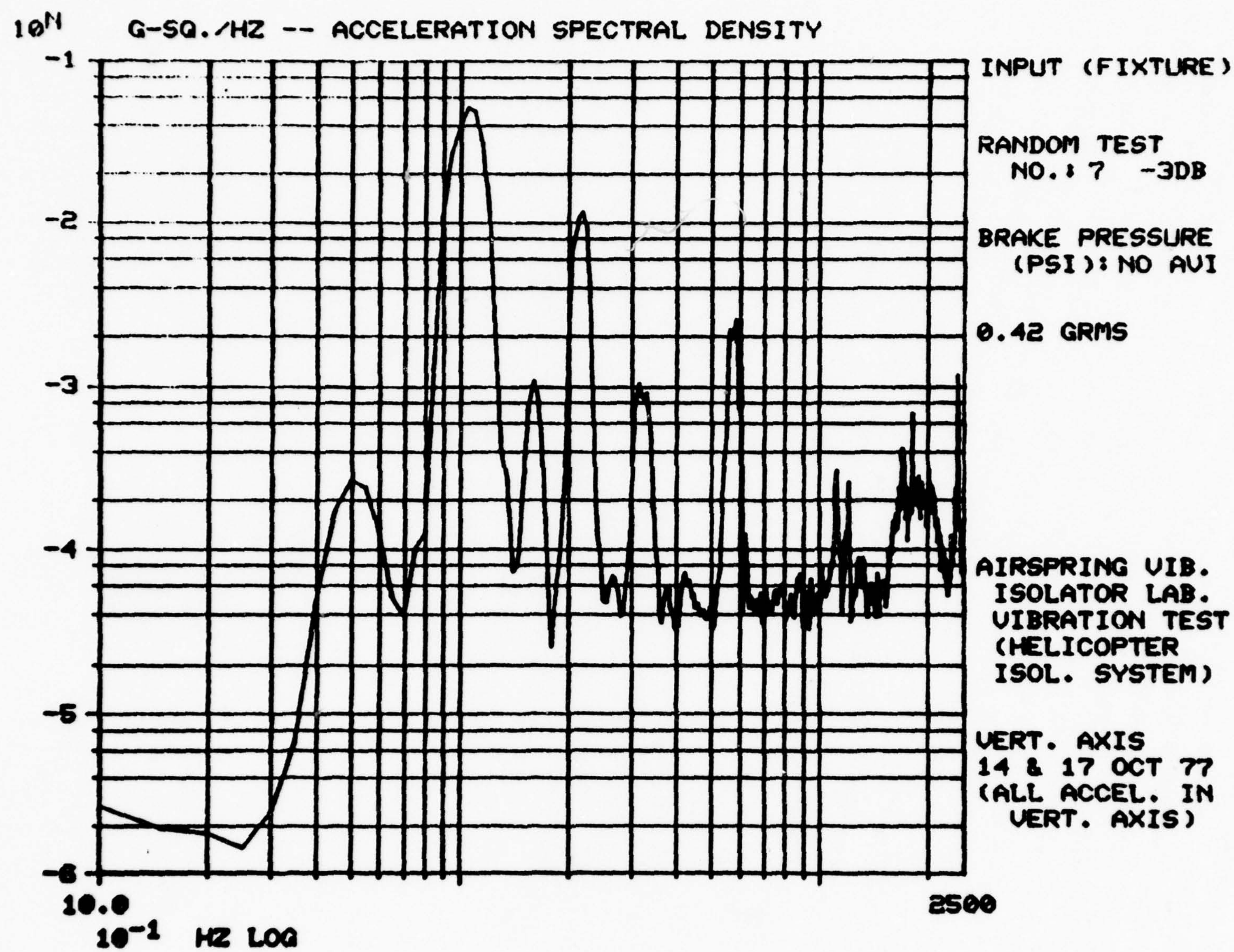

FIGURE 4-2. PSD PLOT OF EXCITATION ACCELERATION SPECTRUM, VERTICAL RANDOM TEST 7

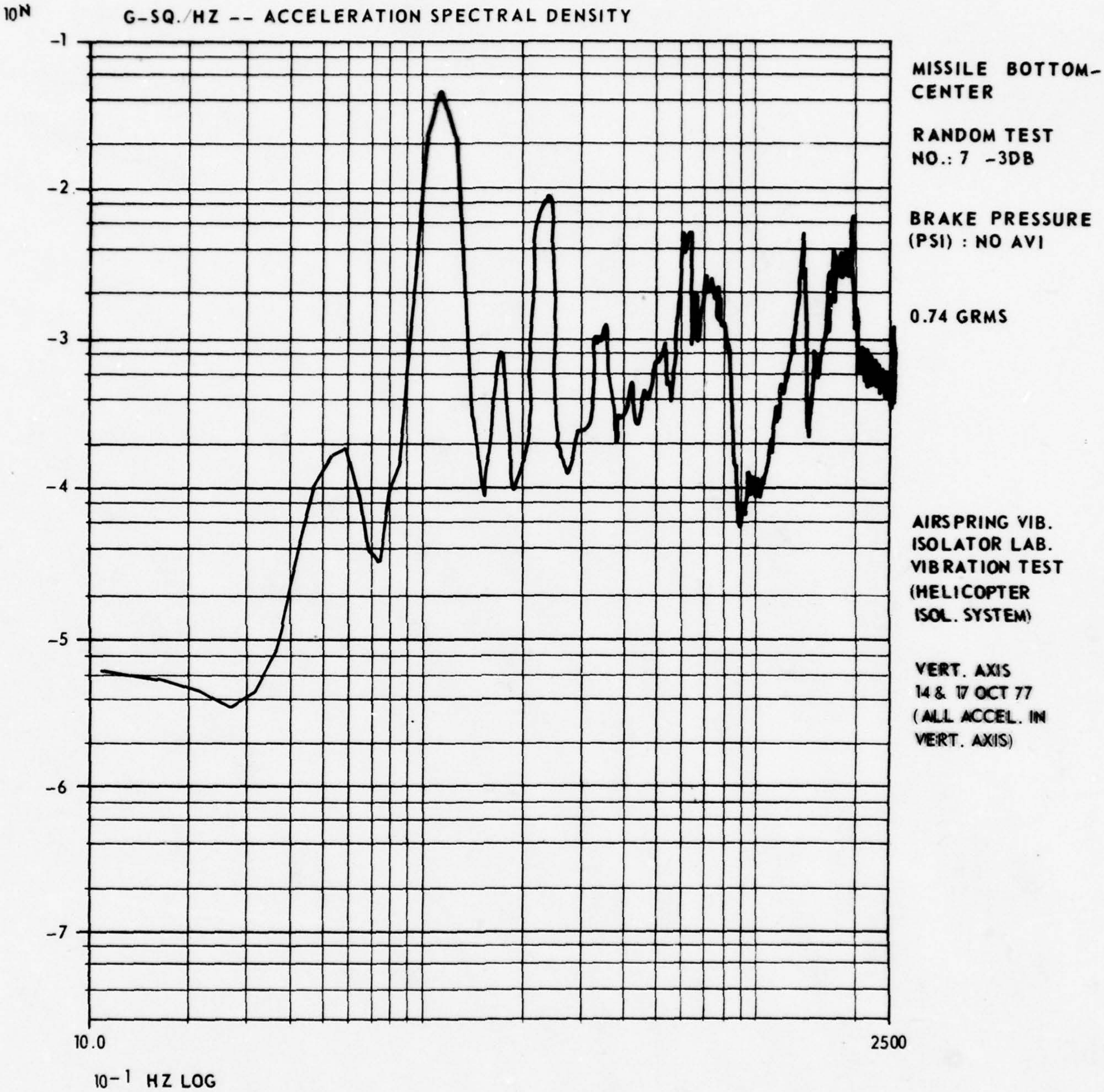

FIGURE 4-4. PSD PLOT OF MISSILE-BOTTOM-CENTER ACCELERATION RESPONSE, VERTICAL RANDOM TEST 7 WITHOUT AVI

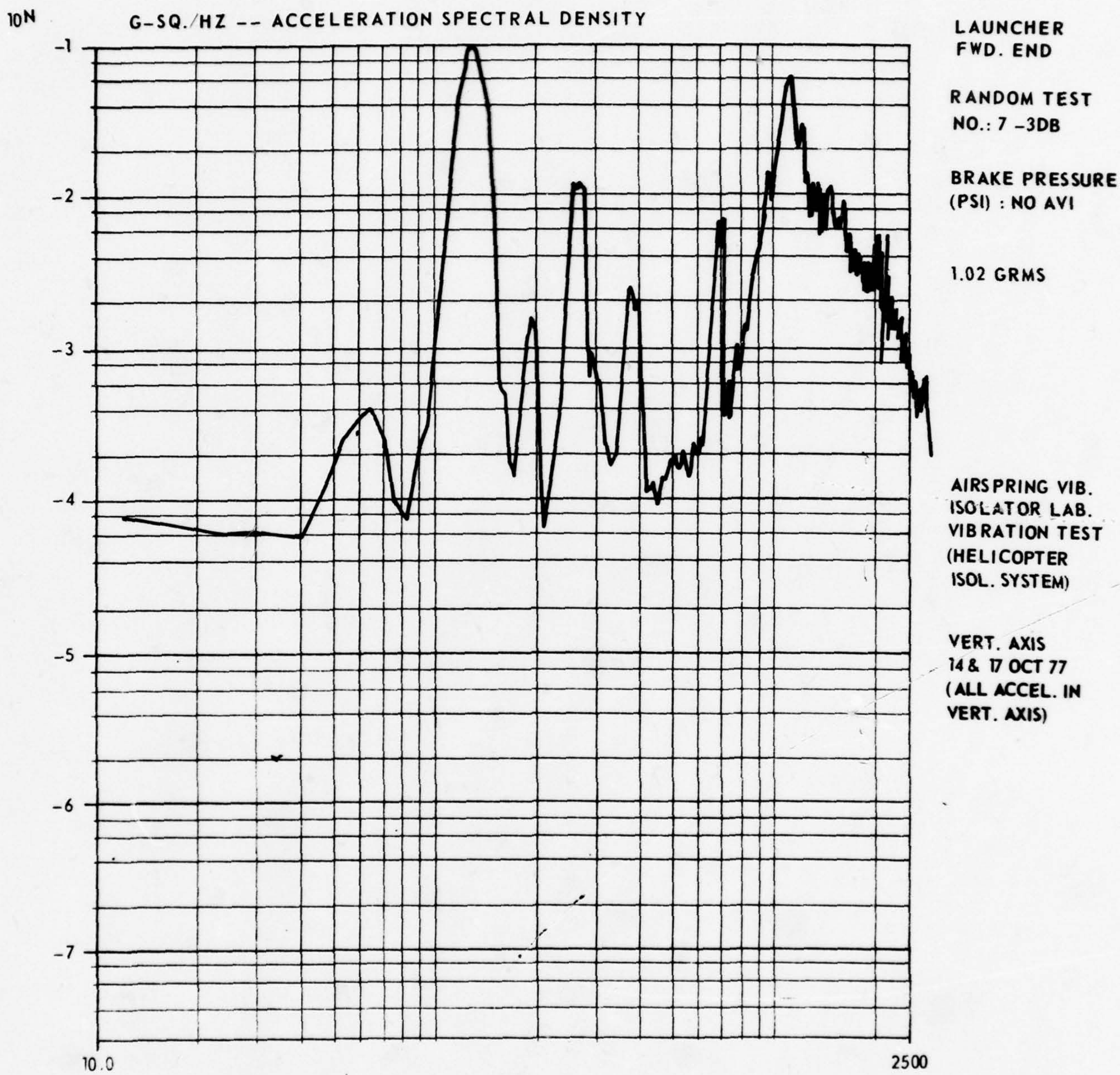

FIGURE 4-6. PSD PLOT OF LAUNCHER-FRONT-END ACCELERATION RESPONSE, VERTICAL RANDOM TEST 7, WITHOUT AVI

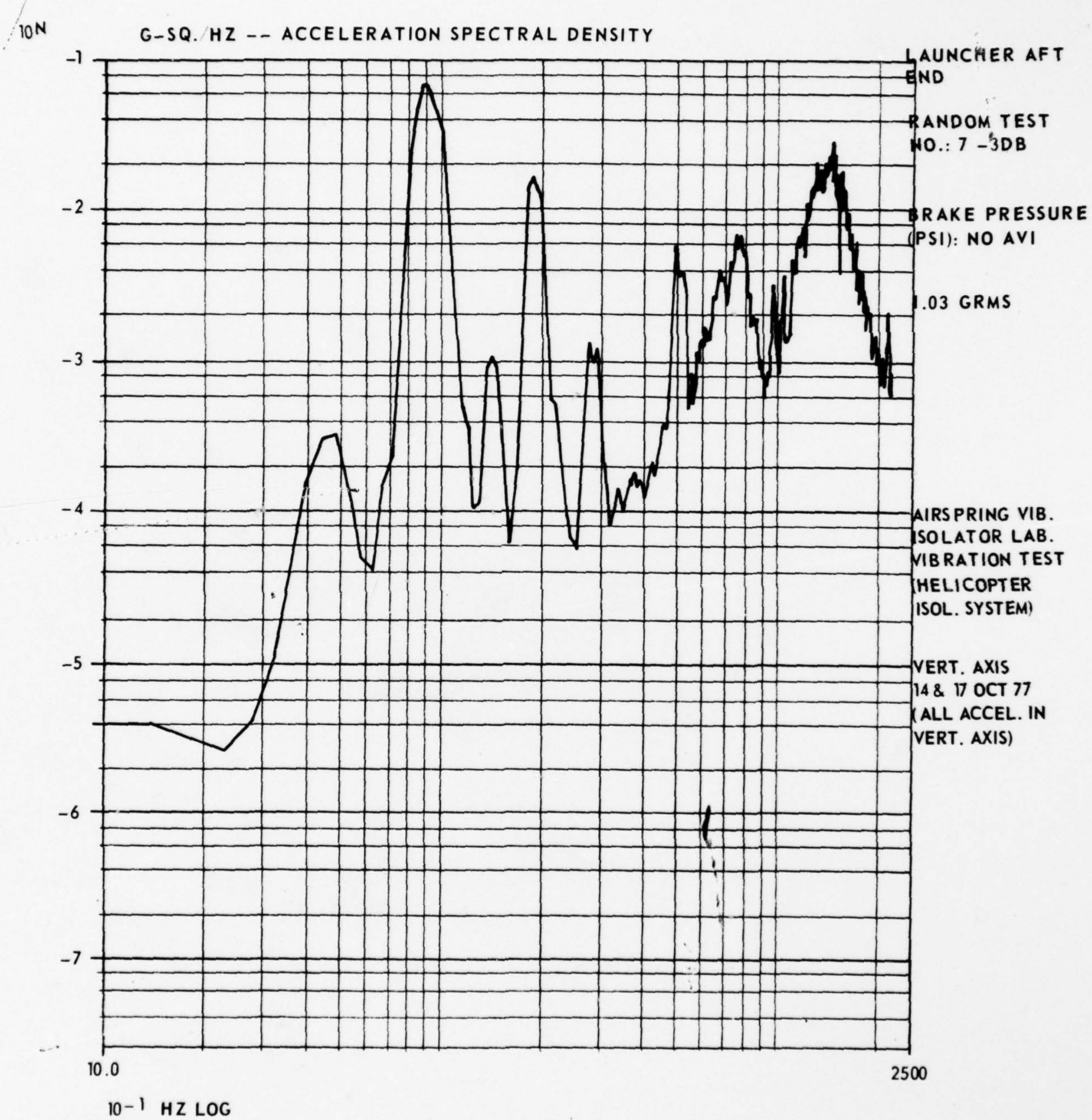

FIGURE 4-8. PSD PLOT OF LAUNCHER-REAR-END ACCELERATION RESPONSE, VERTICAL RANDOM TEST 7, WITHOUT AVI

4.3 COMPARISON OF RESPONSES OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI, VERTICAL SWEEP-SINE TEST RESULTS

The excitation spectra for vertical sweep-sine tests 1, 10, and 10A are shown in Figures 4-9, 4-10 and 4-11, respectively. It is seen that these excitation spectra are almost identical. Vertical sweep-sine test 1 was performed with the launcher-missile system installed under the AVI, while sweep-sine tests 10 and 10A were performed with the same launcher-missile system without the AVI. Three acceleration measurements were obtained for these three tests at identical locations of the launcher-missile system. Typical response/excitation transfer functions for these tests are shown in Figures 4-12 through 4-14. It is seen that the vibration transmissibility with the AVI is significantly less than without the AVI. Tables 4-4 and 4-5 show the comparison of transmissibilities with and without the AVI is significantly larger than with the AVI at these critical frequences. It is also seen that percentage of vibration isolation of the AVI is ranging from 87.1 to 96.7 at these critical frequencies. Here the vibration isolation of the AVI is defined as the ratio of transmissibility without the AVI minus that with the AVI divided by the original transmissibility without the AVI. Thus the results of vertical sweep-sine tests also indicate that the isolation performance of the AVI is excellent along the vertical axis.

TABLE 4-4. COMPARISON OF RESULTS WITH AND WITHOUT AVI, VERTICAL SWEEP-SINE TESTS 1 AND 10

DESCRIPTION	RESULT WITH AVI (A)	RESULT WITHOUT AVI (B)	PERCENTAGE OF ISOLATION (1-B/A) 100
TRANSMISSIBILITY AT 11 HERTZ MISSILE-BOTTOM-CENTER	0.1	1	90
TRANSMISSIBILITY AT 22 HERTZ MISSILE-BOTTOM-CENTER	0.03	0.6	95
TRANSMISSIBILITY AT 33 HERTZ MISSILE-BOTTOM-CENTER	0.023	0.7	96.7
TRANSMISSIBILITY AT 44 HERTZ MISSILE-BOTTOM-CENTER	0.019	1.2	98.4
TRANSMISSIBILITY AT 11 HERTZ LAUNCHER-FRONT-END	0.1	0.98	89.8
TRANSMISSIBILITY AT 22 HERTZ LAUNCHER-FRONT-END	0.04	0.35	88.6
TRANSMISSIBILITY AT 33 HERTZ LAUNCHER-FRONT-END	0.023	0.40	94.3
TRANSMISSIBILITY AT 44 HERTZ LAUNCHER-FRONT-END	0.026	0.50	94.8
TRANSMISSIBILITY AT 11 HERTZ LAUNCHER-REAR-END	0.13	1.02	87.3
TRANSMISSIBILITY AT 22 HERTZ LAUNCHER-REAR-END	0.04	1.1	96.4
TRANSMISSIBILITY AT 33 HERTZ LAUNCHER-REAR-END	0.026	0.6	95.7
TRANSMISSIBILITY AT 44 HERTZ LAUNCHER-REAR-END	0.020	0.6	96.7

TABLE 4-5. COMPARISON OF RESULTS WITH AND WITHOUT AVI, VERTICAL SWEEP-SINE TESTS 1 AND 10A

DESCRIPTION	RESULT WITH AVI (A)	RESULT WITHOUT AVI (B)	PERCENTAGE OF ISOLATION (1-B/A)100
TRANSMISSIBILITY AT 11 HERTZ MISSILE-BOTTOM-CENTER	0.1	1	90
TRANSMISSIBILITY AT 22 HERTZ MISSILE-BOTTOM-CENTER	0.03	0.6	95
TRANSMISSIBILITY AT 33 HERTZ MISSILE-BOTTOM-CENTER	0.023	0.7	96.7
TRANSMISSIBILITY AT 44 HERTZ MISSILE-BOTTOM-CENTER	0.019	1.1	98.3
TRANSMISSIBILITY AT 11 HERTZ LAUNCHER-FRONT-END	0.1	0.98	89.8
TRANSMISSIBILITY AT 22 HERTZ LAUNCHER-FRONT-END	0.04	0.30	86.7
TRANSMISSIBILITY AT 33 HERTZ LAUNCHER-FRONT-END	0.023	0.40	94.3
TRANSMISSIBILITY AT 44 HERTZ LAUNCHER-FRONT-END	0.026	0.50	94.8
TRANSMISSIBILITY AT 11 HERTZ LAUNCHER-REAR-END	0.13	1.01	87.1
TRANSMISSIBILITY AT 22 HERTZ LAUNCHER-REAR-END	0.04	1.2	96.7
TRANSMISSIBILITY AT 33 HERTZ LAUNCHER-REAR-END	0.026	0.64	95.9
TRANSMISSIBILITY AT 44 HERTZ LAUNCHER-REAR-END	0.020	0.6	96.7

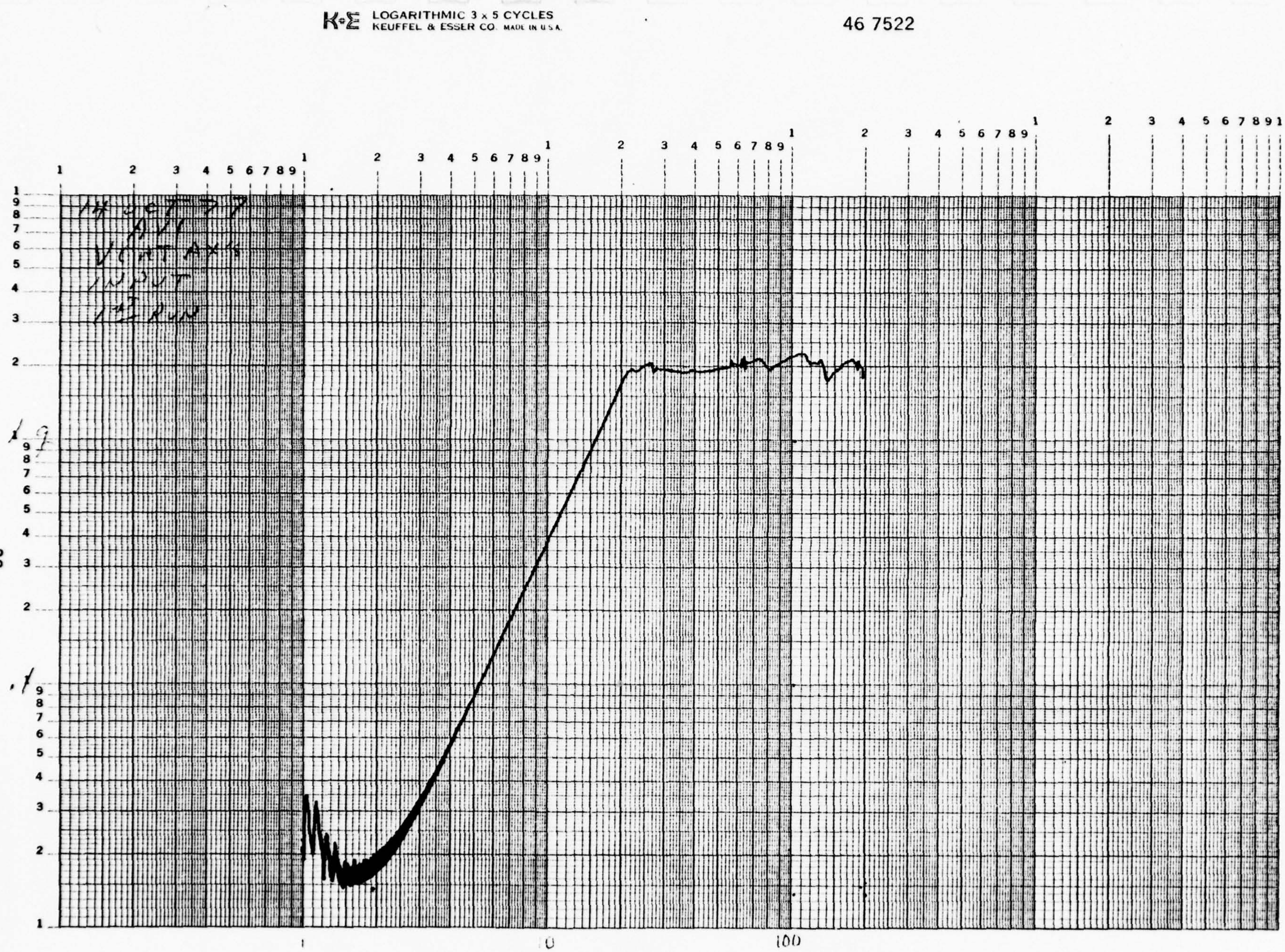

FIGURE 4-9. VERTICAL BASE EXCITATION SPECTRUM, SWEEP-SINE TEST 1

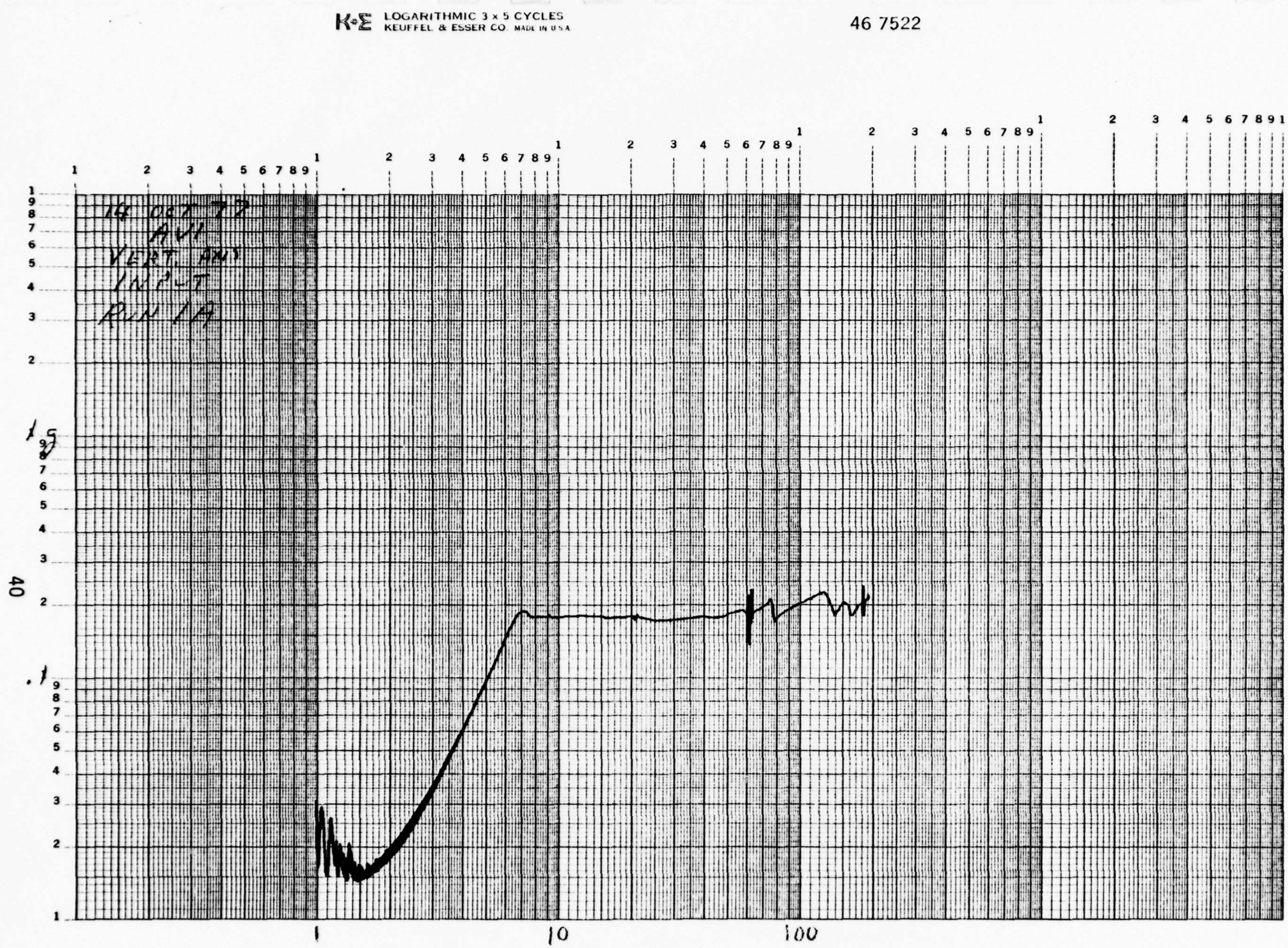

FIGURE 4-10. VERTICAL BASE EXCITATION SPECTRUM, SWEEP-SINE TEST 1A

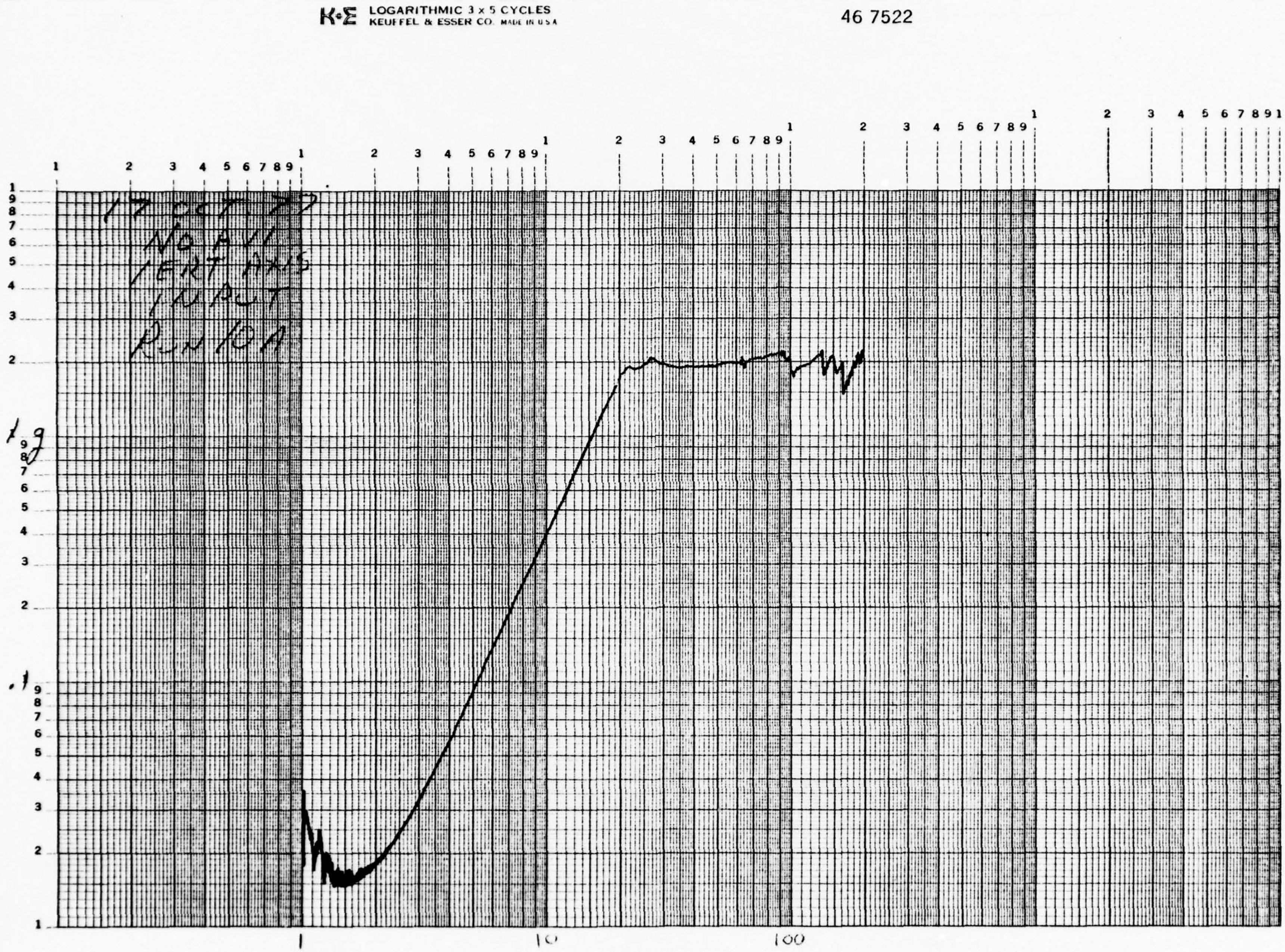

FIGURE 4-11. VERTICAL BASE EXCITATION SPECTRUM, SWEEP-SINE TEST 10A

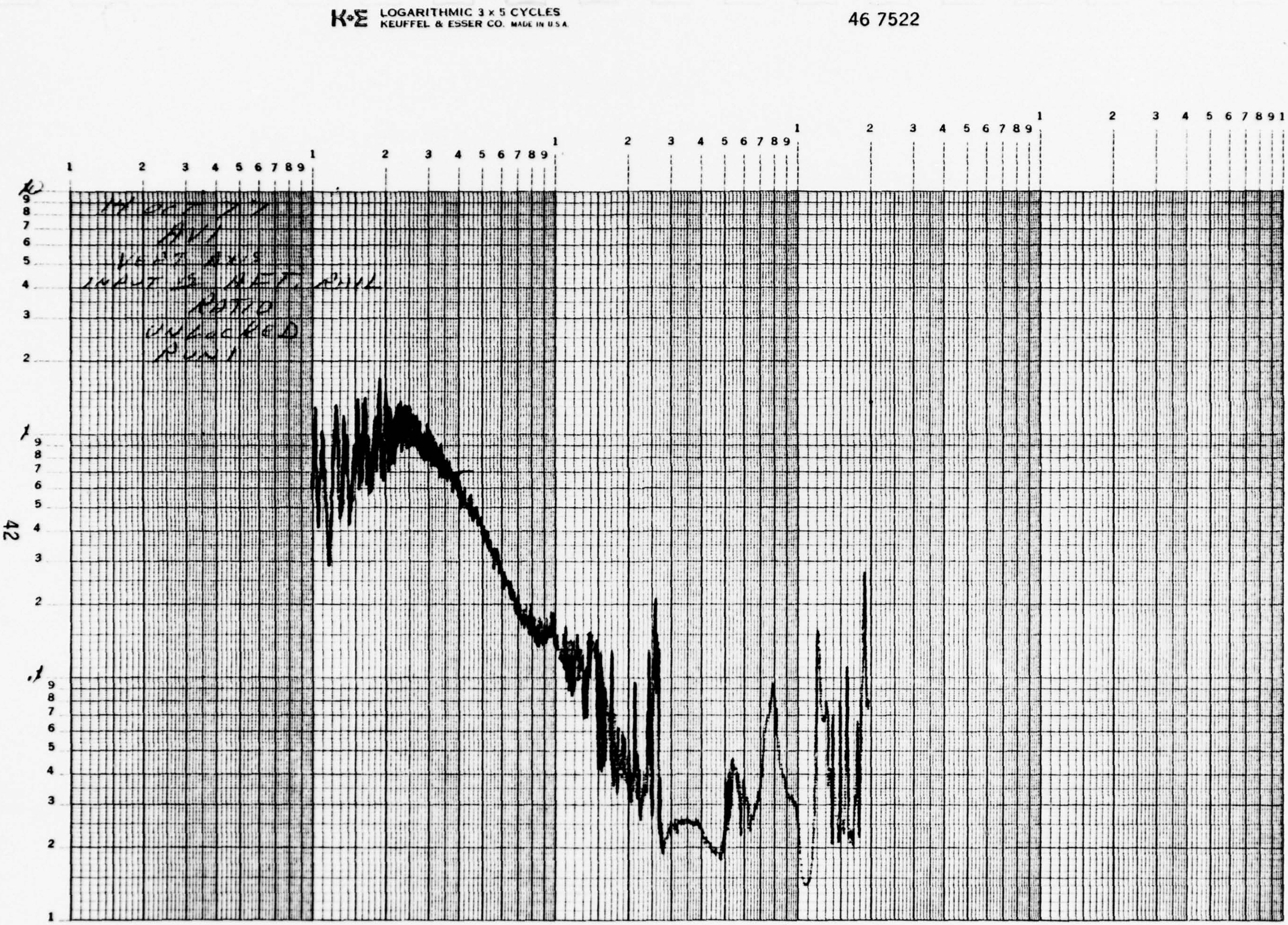

FIGURE 4-12. TRANSFER FUNCTION, LAUNCHER-REAR-END VERTICAL RESPONSE TO VERTICAL EXCITATION AVI UNLOCKED, HIGH G-LEVEL EXCITATION, SWEEP-SINE TEST 1

K·E LOGARITHMIC 3 x 5 CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 7522

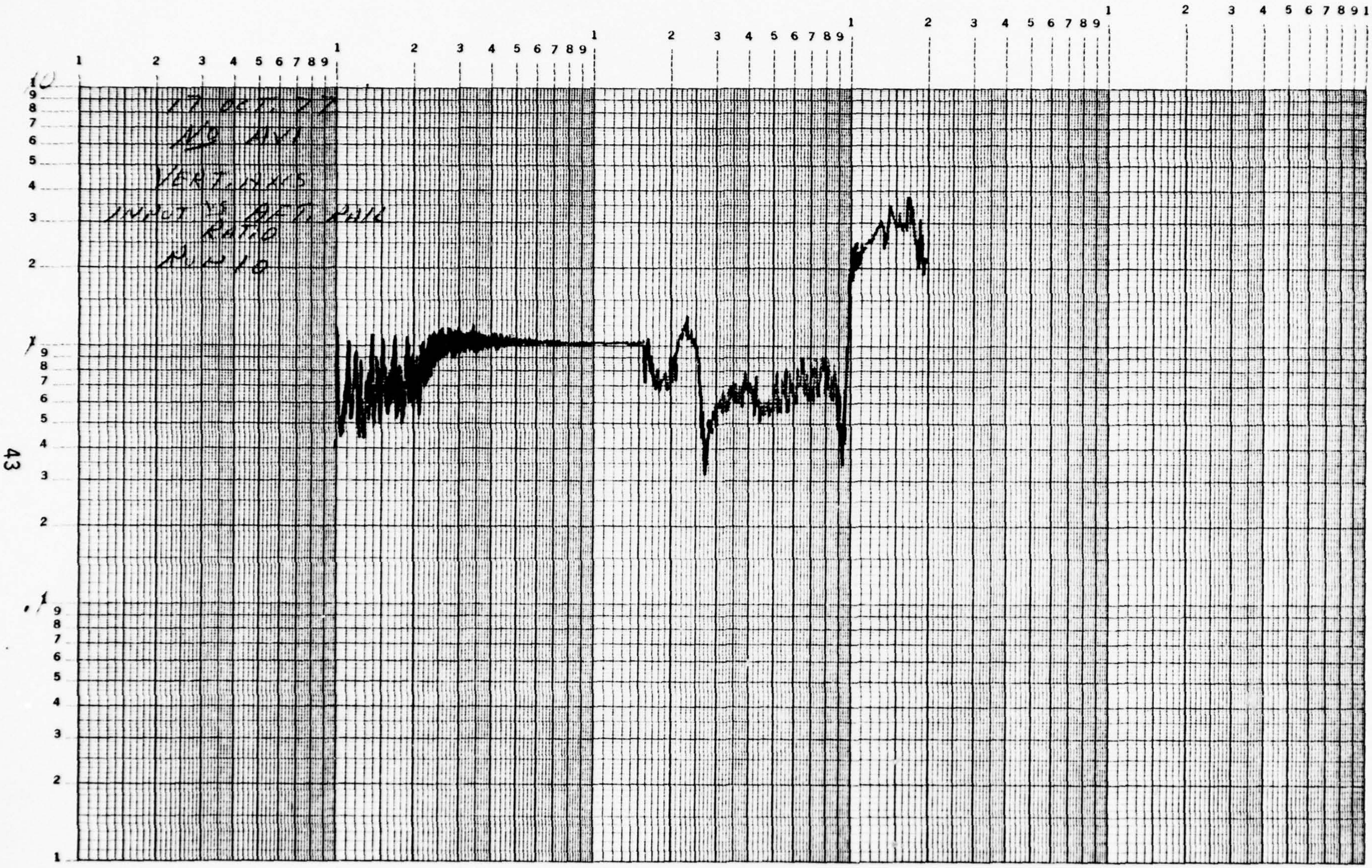

FIGURE 4-13. TRANSFER FUNCTION, LAUNCHER-REAR-END VERTICAL RESPONSE TO VERTICAL EXCITATION WITHOUT AVI, SWEEP-SINE TEST 10

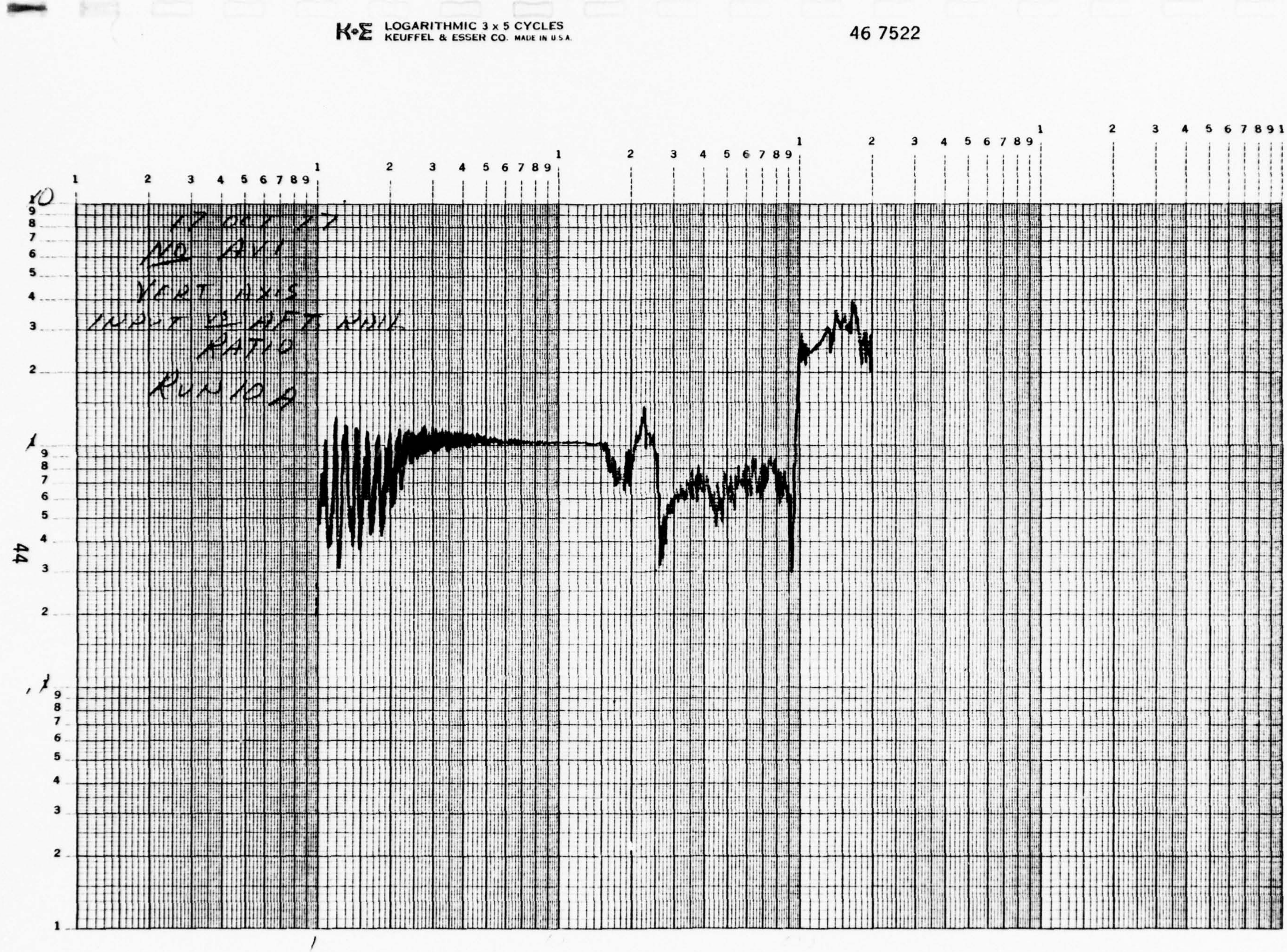

FIGURE 4-14. TRANSFER FUNCTION, LAUNCHER-REAR-END VERTICAL RESPONSE TO VERTICAL EXCITATION WITHOUT AVI, SWEEP-SINE TEST 10A

4.4 ESTIMATION OF VIBRATION LEVELS OF LAUNCHER-MISSILE SYSTEM WITHOUT AVI IN LABORATORY VIBRATION TESTS.

In the AVI laboratory vibration tests, the excitation was controlled to be along one axis, the motion of the AVI-launcher-missile system is not so complex as during the helicopter flight test, and the estimation of the vibration of the launcher-missile system without the AVI from that of the AVI-launcher-missile system is simpler. With the AVI, the center-of-gravity of the launcher-missile system is five (5) inches lower than without the AVI. The center-of-gravity of the AVI-launcher-missile system is 13.425 inches below the bombrack in the pylon. When the AVI-launcher-missile system is locked with 100 psig pressure, the launcher-missile system can be considered a rigid body. Thus for base vibration excitation as in the AVI laboratory longitudinal and transverse vibration tests, the ratio of the vibration level of the launcher-missile system without the AVI to that of the AVI-launcher-missile system in the AVI 100 psig locked condition will be approximately

$$(13.425-5)/13.425 = 0.628$$

Namely, the vibration level of the launcher-missile system without the AVI is 0.628 times that of the AVI-launcher-missile system in the 100 psig locked condition. This is a conservative estimation. The actual vibration level of the launcher-missile system without the AVI will be between one and 0.628 times that of the AVI-launcher-system in the 100 psig locked condition.

When base excitation is applied as in the AVI vertical laboratory vibration tests, where the excitation force passes through the center-of-gravity of the system, the lowering of the center-of-gravity of the system has little effect on the vibration levels of the AVI-launcher-missile

system. Thus the vibration level of the launcher-missile system without the AVI can be assumed to be equal to that of the AVI-launcher-missile system in the 100 psig locked condition. This is evident from Tables 4-6 and 4-7 where composite rms values in acceleration unit are compared between the AVI 100 psig locked condition and the without AVI condition for similar or equal excitations. It is seen that for most of the measured data, the vibration level without the AVI is larger than that of the AVI 100 psig locked condition.

TABLE 4-6 . COMPARISON OF COMPOSITE RMS ACCELERATIONS, AVI 100 PSIG LOCKED AND WITHOUT AVI, VERTICAL RANDOM TESTS 2 AND 7

DESCRIPTION	COMPOSITE RMS ACCELERATION GRMS		RATIO OF RESPONSE TO EXCITATION		RATIO B/A
	TEST 2 AVI 100 PSIG LOCKED	TEST 7 WITHOUT AVI	TEST 4 100 PSIG LOCKED (A)	TEST 8 WITHOUT AVI (B)	
VERTICAL EXCITATION	0.42	0.42			
MISSILE-BOTTOM-CENTER VERTICAL RESPONSE	0.79	0.74	1.8810	1.762	0.937
LAUNCHER-FRONT-END VERTICAL RESPONSE	1.24	1.02	2.9524	2.429	0.823
LAUNCHER-REAR-END VERTICAL RESPONSE	0.96	1.03	2.2857	2.452	1.073

TABLE 4-7 . COMPARISON OF COMPOSITE RMS ACCELERATIONS, AVI 100 PSIG LOCKED AND WITHOUT AVI, VERTICAL RANDOM TESTS 4 AND 8

DESCRIPTION	COMPOSITE RMS ACCELERATION GRMS		RATIO OF RESPONSE TO EXCITATION		RATIO B/A
	TEST 4 AVI 100 PSIG LOCKED	TEST 8 WITHOUT AVI	TEST 4 AVI 100 PSIG LOCKED (A)	TEST 8 WITHOUT AVI (B)	
VERTICAL EXCITATION	0.60	0.63			
MISSILE-BOTTOM-CENTER VERTICAL RESPONSE	1.03	1.65	1.7167	2.6190	1.526
LAUNCHER-FRONT-END VERTICAL RESPONSE	1.71	2.17	2.850	3.4444	1.209
LAUNCHER-REAR-END VERTICAL RESPONSE	1.35	2.01	2.25	3.1905	1.418

4.5 COMPARISON OF RESPONSES OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI, LONGITUDINAL AND TRANSVERSE RANDOM TEST RESULTS

Based on the formulation derived in Secriotn 4.4 the vibration composite rms values of the launcher-missile system without the AVI under random longitudinal base excitation are estimated and the results are shown in Tables 4-8 and 4-9. The percentages of the AVI isolation performance under random laboratory longitudinal base excitations are also estimated in these tables. It is seen that the AVI isolation performance under longitudinal base excitation can be expected to be over 54 percent to as high as 86 percent.

During the AVI laboratory transverse vibration tests, the Government furnished longitudinal isolator was leaking in the piston side. Because of this discrepancy, the data of the AVI transverse vibration tests are not considered sufficiently accurate to draw any conclusion. Thus the estimation of the vibration levels of the launcher-missile system without the AVI under random transverse base excitations can not be performed.

TABLE 4-8 . COMPARISON OF COMPOSITE RMS ACCELERATIONS WITH AND WITHOUT AVI, ESTIMATED FROM LONGITUDINAL RANDOM TESTS 1 AND 2

DESCRIPTION	COMPOSITE RMS ACCELERATION GRMS		RATIO OR RESPONSE TO EXCITATION		PERCENTAGE OF ISOLATION PERFORMANCE 100 (1-A/B)
	TEST 1 WITH AVI	WITHOUT AVI ESTIMATED	WITH AVI (A)	WITHOUT AVI (B)	
LONGITUDINAL EXCITATION	0.41	0.40			
MISSILE-BOTTOM-CENTER LONGITUDINAL RESPONSE	0.057	0.37	0.1390	0.5890	76.1
LAUNCHER-FRONT-END LONGITUDINAL RESPONSE	0.136	0.785	0.3317	1.9625	83.1
LAUNCHER-REAR-END LONGITUDINAL RESPONSE	0.093	0.6406	0.2268	1.6015	85.8

NOTE: Response composite rms acceleration for without AVI is taken as 0.628 times the value for Test 2.

TABLE 4-9 . COMPARISON OF COMPOSITE RMS ACCELERATIONS WITH AND WITHOUT AVI, ESTIMATED FROM LONGITUDINAL RANDOM TESTS 3 AND 4

DESCRIPTION	COMPOSITE RMS ACCELERATION GRMS		RATIO OF RESPONSE TO EXCITATION		
	TEST 3 WITH AVI	WITHOUT AVI ESTIMATED	WITH AVI (A)	WITHOUT AVI (B)	PERCENTAGE OF ISOLATION PERFORMANCE 100 (1-A/B)
LONGITUDINAL EXCITATION	0.55	0.54			
MISSILE-BOTTOM-CENTER LONGITUDINAL RESPONSE	0.112	0.2386	0.2036	0.4419	53.9
LAUNCHER-FRONT-END LONGITUDINAL RESPONSE	0.192	0.8666	0.3491	1.6048	78.2
LAUNCHER-REAR-END LONGITUDINAL RESPONSE	0.115	0.6343	0.201	1.1746	82.2

NOTE: Response composite rms acceleration for without AVI is taken as 0.628 times the value for Test 4.

4.6 AH-1 HELICOPTER FLIGHT VIBRATION DATA FROM OTHER PUBLICATIONS

AH-1 helicopter flight vibration data are available in MICOM technical reports RG-76-30 and RT-TR-69-34 (references 7 and 8). Data from accelerometer measurements 5, 2, and 3 during hovering and 120 knot straight level flight in SMAL configuration 2 flight test in report RG-76-30 are shown in Table 4-10. These data are taken from page 19 in report RG-76-30, Appendix A. Measurement location in report RG-76-30 is fairly close to the launcher-front-end locations in the AVI flight test, the same is true for location 2 with the launcher-rear-end, and location 3 with the AVI-upper-plate-center (see page 13 in report RG-76-30). These data were obtained with a 2-Hertz bandwidth filter centered at the specific frequency, and were the maximum accelerations in g when the data passing through the SD-101 analyzer. Thus, this is the amplitude of a sinusoidal vibration that will have the same energy as the power spectral density of the vibration spectrum. at the specific frequency. The flight vibration data of the launcher-missile system given in report RT-TR-69-34 are similar to those in report RG-76-30.

TABLE 4-10 . AH-1 HELICOPTER FLIGHT VIBRATION DATA FROM MICOM REPORT RG-76-30

CORRESPONDING LOCATION, AXIS AND FREQUENCY IN AVI FLIGHT TEST	LOCATION, AXIS AND FREQUENCY IN REPORT RG-76-30	VIBRATION AMPLITUDE IN "G"	
		HOVERING	120 KNOT STRAIGHT LEVEL FLIGHT
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	T5y, 10.6 HZ	0.080	0.126
LAUNCHER-FRONT-END, TRANSVERSE 22 HZ	T5y, 21.1 HZ	0.102	0.121
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	T5z, 10.6 HZ	0.156	0.198
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	T5z, 21.1 HZ	0.270	0.315
LAUNCHER-REAR-END, TRANSVERSE, 11 HZ	T2Y, 10.6 HZ	0.063	0.077
LAUNCHER-REAR-END, TRANSVERSE, 22 HZ	T2y, 21.1 HZ	0.074	0.116
LAUNCHER-REAR-END, VERTICAL, 11 HZ	T2z, 10.6 HZ	0.127	0.145
LAUNCHER-REAR-END, VERTICAL, 22 HZ	T2z, 21.1 HZ	0.119	0.169
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 11 HZ	T3x, 10.6 HZ	0.136	0.201
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 22 HZ	T3x, 21.1 HZ	0.151	0.141
AVI-UPPER-PLATE-CENTER, VERTICAL, 11 HZ	T3z, 10.6 HZ	0.080	0.058
AVI-UPPER-PLATE-CENTER, VERTICAL, 22 HZ	T3z, 21.1 HZ	0.173	0.205

4.7 DETERMINATION OF SINUSOIDAL AMPLITUDES FROM POWER SPECTRAL DENSITY DATA OF AVI-LAUNCHER-MISSILE SYSTEM DURING FLIGHT TEST

The power-spectral-density data of the AVI-launcher-missile system during the AVI flight test were obtained with a 0.2 Hertz bandwidth filter. The amplitude of the sinusoidal vibration having the same energy as that of the power spectral density of the vibration spectrum at a specific frequency is given by

$$A = (2pb)^{1/2}$$

where p is the psd of the spectrum at the specific frequency, b is the filter bandwidth used to obtain the psd. In Tables 4-11 and 4-12, the power spectral densities for two critical frequencies of the AVI-launcher-missile system during hovering and 60 knot level flight in the AVI flight test were obtained from the available psd plots. In Tables 4-13 and 4-14, the corresponding sinusoidal amplitudes of the power spectral densities in Tables 4-11 and 4-12 were determined with the above formulas. The purpose of this conversion is to facilitate the comparison of the AVI flight test data with those given in references 7 and 8.

TABLE 4-11. VIBRATION POWER-SPECTRAL-DENSITIES OF AVI-LAUNCHER-MISSILE SYSTEM DURING FLIGHT TEST, HOVERING

LOCATION, AXIS AND FREQUENCY	POWER SPECTRAL DENSITY IN G^2/HZ		
	AVI UNLOCKED	AVI 5 PSIG LOCKED	AVI 100 PSIG LOCKED
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	0.00022	0.0008	0.00033
LAUNCHER-FRONT-END, TRANSVERSE, 22 HZ	0.0015	0.002	0.005
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	0.004	0.008	0.1
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	0.01	0.01	0.02
LAUNCHER-REAR-END, TRANSVERSE, 11 HZ	0.00065	0.0006	0.0006
LAUNCHER-REAR-END, TRANSVERSE, 22 HZ	0.0032	0.005	0.008
LAUNCHER-REAR-END, VERTICAL, 11 HZ	0.0023	0.0032	0.06
LAUNCHER-REAR-END, VERTICAL, 22 HZ	0.0075	0.0068	0.051
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.0003	0.00061	0.000042
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0016	0.003	0.00028
AVI-LOWER-PLATE-CENTER, VERTICAL, 11 HZ	0.00016	0.0006	0.055
AVI-LOWER-PLATE-CENTER, VERTICAL, 22 HZ	0.000027	0.00007	0.0023
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 11 HZ	0.00061	0.001	0.00061
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 22 HZ	0.00063	0.0008	0.00081
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.00013	0.00029	0.00008
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0009	0.0017	0.0005
AVI-UPPER-PLATE-CENTER, VERTICAL, 11 HZ	0.016	0.04	0.018
AVI-UPPER-PLATE-CENTER, VERTICAL, 22 HZ	0.006	0.008	0.013

TABLE 4-12 . VIBRATION POWER SPECTRAL DENSITY OF AVI-LAUNCHER-MISSILE SYSTEM DURING FLIGHT TEST, 60 KNOT LEVEL FLIGHT

LOCATION, AXIS AND FREQUENCY	POWER SPECTRAL DENSITY IN G^2/Hz		
	AVI UNLOCKED	AVI 5 PSIG LOCKED	AVI 100 PSIG LOCKED
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	0.0016	0.0016	0.003
LAUNCHER-FRONT-END, TRANSVERSE, 22 HZ	0.00061	0.0006	0.0043
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	0.006	0.0034	0.13
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	0.0091	0.017	0.081
LAUNCHER-REAR-END, TRANSVERSE, 11 HZ	0.0024	0.0022	0.0033
LAUNCHER-REAR-END, TRANSFERSE, 22 HZ	0.00081	0.0012	0.012
LAUNCHER-REAR-END, VERTICAL, 11 HZ	0.016	0.012	0.02
LAUNCHER-REAR-END, VERTICAL, 22 HZ	0.008	0.013	0.033
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.0026	0.0023	0.00066
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0006	0.008	0.0015
AVI-LOWER-PLATE-CENTER, VERTICAL, 11 HZ	0.00045	0.00048	0.12
AVI-LOWER-PLATE-CENTER, VERTICAL, 22 HZ	0.00008	0.000082	0.033
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 11 HZ	0.0041	0.0028	0.0045
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 22 HZ	0.0032	0.004	0.0012
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.0022	0.0021	0.00065
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0008	0.00062	0.0022
AVI-UPPER-PLATE-CENTER, VERTICAL, 11 HZ	0.08	0.07	0.044
AVI-UPPER-PLATE CENTER, VERTICAL, 22 HZ	0.065	0.06	0.012

TABLE 4-13 . VIBRATION ACCELERATION AMPLITUDES OF AVI-LAUNCHER-MISSILE SYSTEM AT CRITICAL FREQUENCIES DURING FLIGHT TEST, HOVERING

LOCATION, AXIS AND FREQUENCY	ACCELERATION AMPLITUDE IN G		
	UNLOCKED	AVI 5 PSIG LOCKED	AVI 100 PSIG LOCKED
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	0.00938	0.0179	0.0115
LAUNCHER-FRONT-END, TRANSVERSE, 22 HZ	0.0245	0.0283	0.0447
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	0.040	0.0566	0.20
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	0.632	0.0632	0.0894
LAUNCHER-REAR-END, TRANSVERSE, 11 HZ	0.0161	0.0155	0.0155
LAUNCHER-REAR-END, TRANSVERSE, 22 HZ	0.0358	0.0447	0.056
LAUNCHER-REAR-END, VERTICAL, 11 HZ	0.0303	0.0358	0.155
LAUNCHER-REAR-END, VERTICAL, 22 HZ	0.0548	0.0522	0.143
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.0110	0.0156	0.0041
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0253	0.0346	0.0106
AVI-LOWER-PLATE-CENTER, VERTICAL, 11 HZ	0.008	0.0155	0.148
AVI-LOWER-PLATE-CENTER, VERTICAL, 22 HZ	0.00329	0.00529	0.0303
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 11 HZ	0.0156	0.020	0.0156
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 22 HZ	0.0159	0.0179	0.0180
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.00721	0.0108	0.00566
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0190	0.0261	0.0141
AVI-UPPER-PLATE-CENTER, VERTICAL, 11 HZ	0.080	0.126	0.0849
AVI-UPPER-PLATE-CENTER, VERTICAL, 22 HZ	0.0490	0.0566	0.0721

TABLE 4-14 . VIBRATION ACCELERATION AMPLITUDES (IN G) OF AVI-LAUNCHER-MISSILE SYSTEM AT CRITICAL FREQUENCIES DURING FLIGHT TEST, 60 KNOT LEVEL FLIGHT

LOCATION, AXIS AND FREQUENCY	ACCELERATION AMPLITUDE IN G		
	AVI UNLOCKED	AVI 5 PSIG LOCKED	AVI 100 PSIG LOCKED
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	0.0253	0.0253	0.0346
LAUNCHER-FRONT-END, TRANSVERSE, 22 HZ	0.0156	0.0155	0.0415
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	0.0490	0.0369	0.228
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	0.0603	0.0825	0.180
LAUNCHER-REAR-END, TRANSVERSE, 11 HZ	0.0310	0.0297	0.0363
LAUNCHER-REAR-END, TRANSVERSE, 22 HZ	0.018	0.0219	0.0693
LAUNCHER-REAR-END, VERTICAL, 11 HZ	0.080	0.0693	0.283
LAUNCHER-REAR-END, VERTICAL, 22 HZ	0.0566	0.0721	0.115
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.0322	0.0303	0.0162
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0155	0.0179	0.0245
AVI-LOWER-PLATE-CENTER, VERTICAL, 11 HZ	0.0134	0.0139	0.219
AVI-LOWER-PLATE-CENTER, VERTICAL, 22 HZ	0.00566	0.00573	0.115
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 11 HZ	0.0405	0.0335	0.0424
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 22 HZ	0.0358	0.040	0.0219
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.0297	0.0290	0.0161
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0179	0.0157	0.0297
AVI-UPPER-PLATE-CENTER, VERTICAL, 11 HZ	0.179	0.167	0.133
AVI-UPPER-PLATE-CENTER, VERTICAL, 22 HZ	0.161	0.155	0.0693

4.8 ESTIMATE OF VIBRATION LEVELS OF LAUNCHER-MISSILE SYSTEM WITHOUT THE AVI FROM DATA WITH THE AVI, FLIGHT TEST DATA

Since the same launcher-missile system was not flown without the AVI in the AVI flight test, no vibration data of the launcher-missile system without the AVI are available to compare with those with the AVI installed. However, the vibration levels of the launcher-missile system without the AVI can be approximately estimated from the vibration data of the AVI-launcher-missile system in the AVI 100 psig locked condition. With the AVI installed the center-of-gravity of the launcher-missile system is five (5) inches lower than without the AVI, which is small as compared to the distance from the center-of-gravity of the helicopter to that of the launcher-missile system. If the helicopter stub-wing, the launcher-missile system, the interface between them, and the AVI locking system are absolutely rigid, then as far as rotor-induced vibrations are concerned, the vibration levels of the launcher-missile system without the AVI will be practically the same as those of the AVI-launcher-missile system in the 100 psig locked condition. However, the helicopter stub-wing, the launcher-missile system, the interface between them, and the AVI locking system are elastic to a certain extent. In addition to rotor-induced vibrations, the launcher-missile system is also directly excited by the relative air stream it encounters during flight. This significantly complicates the dynamics of the launcher-missile system such that vibration levels of the launcher-missile system without the AVI may be in some cases larger than the AVI-launcher-missile system in the 100 psig locked condition and in another case may be smaller. In Tables 4-15, sinusoidal vibration amplitudes of the AVI-launcher-missile system in the AVI 100 psig locked condition during the AVI flight test (see Section 4.7) are compared with similar data from Report RG-76-30 (see Section 4.6). It is

seen that most of the data from report RG-76-30 are significantly larger than than the AVI flight test data. It is also seen that several of the AVI flight test data are slightly larger than those from report RG-76-30. This is because that data in report RG-76-30 were the maximum level and that the vibrations of the launcher-missile system are random in nature and the measured vibration levels can be scattering to a very large extent. From the above discussion and the comparison in Table 4-15 it is considered plausible to assume that the vibration levels of the launcher-missile system without the AVI is equal to those of the AVI-launcher-missile system in the AVI 100 psig locked condition.

TABLE 4-15 . COMPARISON OF VIBRATION AMPLITUDES (IN G) OF AVI-LAUNCHER-MISSILE SYSTEM DURING FLIGHT TEST WITH SIMILAR DATA FROM REPORT RG-76-34

LOCATION, AXIS, AND FREQUENCY	HOVERING		60 KNOT LEVEL FLIGHT AVI 100 PSIG LOCKED	120 KNOT STRAIGHT LEVEL FLIGHT REPORT RG-76-30
	AVI 100 PSIG LOCKED	SIMILAR DATA IN RG-76-30		
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	0.0115	0.080	0.0346	0.126
LAUNCHER-FRONT-END, TRANSVERSE, 22 HZ	0.0447	0.102	0.0415	0.121
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	0.20	0.156	0.228	0.198
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	0.0894	0.270	0.180	0.315
LAUNCHER-REAR-END, TRANSVERSE 11 HZ	0.0155	0.063	0.0363	0.077
LAUNCHER-REAR-END, TRANSVERSE, 22 HZ	0.0566	0.074	0.0693	0.116
LAUNCHER-REAR-END, VERTICAL, 11 HZ	0.155	0.127	0.283	0.145
LAUNCHER-REAR-END, VERTICAL, 22 HZ	0.143	0.119	0.115	0.169
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 11 HZ	0.0041		0.0162	
AVI-LOWER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0106		0.0245	
AVI-LOWER-PLATE-CENTER, VERTICAL, 11 HZ	0.148		0.219	
AVI-LOWER-PLATE-CENTER, VERTICAL, 22 HZ	0.0303		0.115	
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 11 HZ	0.0156	0.136	0.0424	0.201
AVI-UPPER-PLATE-CENTER, LONGITUDINAL, 22 HZ	0.0180	0.151	0.0219	0.141
AVI-UPPER-PLATE-CENTER, TRANSVERSE 11 HZ	0.00566		0.0161	
AVI-UPPER-PLATE-CENTER, TRANSVERSE, 22 HZ	0.0141		0.0297	
AVI-UPPER-PLATE-CENTER, VERTICAL, 11 HZ	0.0849	0.080	0.133	0.058
AVI-UPPER-PLATE-CENTER, VERTICAL, 22 HZ	0.0721	0.173	0.0693	0.205

4.9 COMPARISON OF LAUNCHER-MISSILE VIBRATIONS WITH AND WITHOUT AVI DURING HELICOPTER FLIGHT

With sinusoidal amplitudes of the AVI-launcher-missile system vibrations determined from vibration power spectral densities as in Section 4.7, helicopter flight vibration data from other publications obtained as in Section 4.6 and vibration levels of launcher-missile system without t the AVI estimated as in Section 4.8, the comparison of vibration levels of the launcher-missile system with and without the AVI can be performed. In Tables 4.16 and 4.17, the composite rms values in acceleration unit of the launcher-missile vibrations during flight with and without the AVI at the launcher front and rear ends are compared. It is seen that the composite rms values in accelerations unit without the AVI are significantly larger than with the AVI. As composite rms values in acceleration unit are concerned, the vibration isolation percentage is 47 to 75. Here is the isolation percentage is defined as the percentage of the reduction of rms acceleration with the AVI as compared to without the AVI. In references 7 and 8, the vibration data of the launcher-missile system are given in vibration amplitudes at specific frequencies and there are no composite rms values available. Thus the AVI flight test data and those in reference 7 can only be compared in vibration amplitudes at specific frequencies. This is done in Tables 4-18 and 4-19 for two critical frequencies, 11 and 22 Hertz, at the launcher front and rear ends. It is seen that most of the vibration amplitudes without the AVI either from reference 7 or estimated from the AVI flight test data are significantly larger than with the AVI installed. Since the vibrations of the launcher-missile system during flight are random in nature, thus the vibration amplitudes at specific frequencies are also random in nature.

This explains why one of the estimated amplitudes with the AVI is slightly larger than without the AVI. Comparisons of accurate results can only be performed when vibration data without the AVI are obtained in future helicopter flight tests.

TABLE 4-16. . COMPARISON OF RESPONSE COMPOSITE RMS ACCELERATION OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI DURING FLIGHT, HOVERING

RESPONSE LOCATION AND AXIS	COMPOSITE RMS ACCELERATION IN "G"		ISOLATION IMPROVEMENT DUE TO AVI (B/A)	ISOLATION PERCENTAGE (1-A/B)100
	WITH AVI (A)	WITHOUT AVI ESTIMATED (B)		
LAUNCHER-FRONT-END, TRANSVERSE	0.071	0.170	2.394	58.2
LAUNCHER-FRONT-END, VERTICAL	0.201	0.421	2.095	52.3
LAUNCHER-READ-END, TRANSVERSE	0.064	0..259	4.047	75.3
LAUNCHER-REAR-END, VERTICAL	0.187	0.354	1.893	47.2

TABLE 4-17 . COMPARISON OF RESPONSE COMPOSITE RMS ACCELERATION OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI DURING FLIGHT, 60 KNOT LEVEL FLIGHT

RESPONSE LOCATION AND AXIS	COMPOSITE RMS ACCELERATION IN "G"		ISOLATION IMPROVEMENT DUE TO AVI (B/A)	ISOLATION PERCENTAGE $(1 - \frac{A}{B})$ 100
	WITH AVI (A)	WITHOUT AVI ESTIMATED (B)		
LAUNCHER-FRONT-END, TRANSVERSE	0.068	0.197	2.897	65.5
LAUNCHER-FRONT-END, VERTICAL	0.160	0.429	2.681	62.7
LAUNCHER-REAR-END, TRANSVERSE	0.066	0.247	3.742	73.3
LAUNCHER-REAR-END, VERTICAL	0.154	0.393	2.552	60.8

TABLE 4-18 . COMPARISON OF VIBRATION AMPLITUDES OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI, HOVERING

LOCATION, AXIS, AND FREQUENCY	VIBRATION AMPLITUDE IN G			ISOLATION IMPROVEMENT DUE TO AVI B/A	ISOLATION IMPROVEMENT DUE TO AVI C/A
	WITH AVI A	WITHOUT AVI ESTIMATED B	DATA FROM REPORT RG-76-30 C		
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	0.00938	0.0115	0.080	1.226	8.529
LAUNCHER-FRONT-END, TRANSVERSE, 22 HZ	0.0245	0.0447	0.102	1.824	4.163
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	0.040	0.20	0.156	5.0	3.90
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	0.063	0.0894	0.270	1.415	4.272
LAUNCHER-REAR-END, TRANSVERSE, 11 HZ	0.0161	0.0155	0.063	0.963	3.913
LAUNCHER-REAR-END, TRANSVERSE, 22 HZ	0.0358	0.056	0.074	1.564	2.067
LAUNCHER-REAR-END, VERTICAL, 11 HZ	0.0303	0.155	0.127	5.116	4.191
LAUNCHER-REAR-END, VERTICAL, 22 HZ	0.0548	0.143	0.119	2.609	2.172

TABLE 4-19 . COMPARISON OF VIBRATION AMPLITUDES OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI, LEVEL FLIGHT

LOCATION, AXIS, AND FREQUENCY	VIBRATION AMPLITUDE IN G			ISOLATION IMPROVEMENT DUE TO AVI B/A	ISOLATION IMPROVEMENT DUE TO AVI C/A
	WITH AVI A	WITHOUT AVI ESTIMATED B	DATA FROM REPORT RG-76-30 C		
LAUNCHER-FRONT-END, TRANSVERSE, 11 HZ	0.0253	0.0346	0.126	1.368	4.980
LAUNCHER-FRONT-END, TRANSVERSE, 22 HZ	0.0156	0.0415	0.121	2.660	7.756
LAUNCHER-FRONT-END, VERTICAL, 11 HZ	0.0490	0.228	0.198	4.653	4.041
LAUNCHER-FRONT-END, VERTICAL, 22 HZ	0.0603	0.180	0.315	2.985	5.224
LAUNCHER-REAR-END, TRANSVERSE, 11 HZ	0.0310	0.0363	0.077	1.171	2.484
LAUNCHER-REAR-END, TRANSVERSE, 22 HZ	0.018	0.0693	0.116	3.85	6.444
LAUNCHER-REAR-END, VERTICAL, 11 HZ	0.080	0.283	0.145	3.538	1.813
LAUNCHER-REAR-END, VERTICAL, 22 HZ	0.0566	0.115	0.169	2.032	2.986

4.10 REDUCTION OF DYNAMIC LOADS OF LAUNCHER-MISSILE SYSTEM ON THE HELICOPTER STUB-WING BY AVI

When the launcher-missile system vibrates, it produces dynamic load on the helicopter stub-wing. The dynamic load produced by a mass element dm having an acceleration G is

$$df = Gdm \qquad (1)$$

When the mass element vibrates in a random nature with a spectrum covering a range of frequencies as that of the helicopter during flight. The dynamic load has to be determined in a statistical sense by substituting the composite rms acceleration for G in equation 1. Thus for a mass element vibrating randomly the dynamic load is proportional to the composite rms acceleration of the random vibration. With the composite rms values in acceleration unit of the launcher-missile system without the AVI estimated as in Section 4.4, the reduction of dynamic loads of the launcher-missile system on the helicopter stub-wing due to the AVI can be estimated. The results are shown in Tables 4.20 and 4-21 for hovering and 60 knot level flight at three locations of the launcher. It is seen that the extra dynamic loads without the AVI are significantly larger than with the AVI. Thus by reducing the vibration levels, the AVI also reduces the dynamic load of the launcher-missile system on the helicopter stub-wing. As can be seen in these tables, the extra dynamic loads due to vibrations are different at different locations of the launcher-missile system. When the helicopter is in flight, the loads exerted on the stub-wing by the launcher-missile system can be resolved into three forces and three moments along and about any three orthogonal axes. These resultant forces and movements can be calculated by integration of summation. As examples of the calculation, let the launcher-missile system be divided into three sections, the front, the center, and

the rear, and let 0.25 of the total mass belongs to each of the front and the rear sections and 0.5 of the total mass belongs to the center section. Then for 60 knot level flight with the AVI, the total extra vertical dynamic load the launcher-missile system exerting on the stub-wing will be

$$(0.160 + 0.154)\ 0.25 + 0.043 \times 0.5 = 0.10\ G$$

and for without the AVI, the total extra vertical dynamic load is

$$(0.429 + 0.395)\ 0.25 + 0.259 \times 0.5 = 0.335\ G$$

Thus during 60 knot level flight the extra dynamic load due to vibration is 3.35 times as large as with the AVI. The total vertical load that the launcher-missile system exerting on the stub-wing is the static load plus the extra dynamic load due to vibrations.

Comparison of dynamic loads of the launcher-missile system on the helicopter stub-wing is shown in Table 4-22 for both hovering and 60 knot level flight and for the transverse and the vertical axes. It is seen that the dynamic loads without the AVI are significantly larger than with the AVI. The percentage of reduction of dynamic loads by the AVI as compared to without the AVI is 45 percent to 70 percent.

TABLE 4-20 . COMPARISON OF ESTIMATED TOTAL EXTRA DYNAMIC LOADS OF LAUNCHER-MISSILE SYSTEM ON HELICOPTER STUB-WING DURING FLIGHT

FLIGHT CONDITION AND AXIS	TOTAL EXTRA DYNAMIC LOAD IN "G"		RATIO OF TOTAL DYNAMIC LOADS WITHOUT AVI TO WITH AVI (B/A)
	WITH AVI (A)	WITHOUT AVI ESTIMATED (B)	
HOVERING, TRANSVERSE	0.0538	0.162	3.011
HOVERING, VERTICAL	0.155	0.288	1.858
60 KNOT LEVEL FLIGHT, TRANSFERSE	0.058	0.167	2.87
60 KNOT LEVEL FLIGHT, VERTICAL	0.1	0.335	3.35

TABLE 4-21 . ESTIMATED EXTRA DYNAMIC LOADS OF LAUNCHER-MISSILE SYSTEM ON HELICOPTER STUB-WING DURING 60 KNOT LEVEL FLIGHT

RESPONSE LOCATION AND AXIS	EXTRA DYNAMIC LOAD DUE TO VIBRATION IN "G"		RATIO OF EXTRA DYNAMIC LOADS WITHOUT AVI TO WITH AVI (B/A)
	WITH AVI (A)	WITHOUT AVI ESTIMATED (B)	
LAUNCHER-FRONT-END, TRANSVERSE	0.068	0.197	2.897
LAUNCHER-FRONT-END, VERTICAL	0.160	0.429	2.681
LAUNCHER-REAR-END, TRANSVERSE	0.066	0.247	3.742
LAUNCHER-REAR-END, VERTICAL	0.154	0.393	2.552
LAUNCHER-CENTER, TRANSVERSE	0.049	0.111	2.265
LAUNCHER-CENTER, VERTICAL	0.043	0.259	6.023

TABLE 4-22 . ESTIMATED EXTRA DYNAMIC LOADS OF LAUNCHER-MISSILE SYSTEM ON HELICOPTER STUB-WING DURING HOVERING

RESPONSE LOCATION AND AXIS	EXTRA DYNAMIC LOAD DUE TO VIBRATION IN "G"		PERCENTAGE OF REDUCTION OF DYNAMIC LOAD
	WITH AVI (A)	WITHOUT AVI ESTIMATED (B)	
LAUNCHER-FRONT-END, TRANSVERSE	0.071	0.170	66.8
LAUNCHER-FRONT-END, VERTICAL	0.201	0.421	46.2
LAUNCHER-REAR-END, TRANSVERSE	0.064	0.259	65.3
LAUNCHER-REAR-END, VERTICAL	0.187	0.354	70.1
LAUNCHER-CENTER, TRANSVERSE	0.040	0.109	
LAUNCHER-CENTER, VERTICAL	0.116	0.189	

4.11 COMPARISON OF PITCH AND YAW VIBRATIONS OF LAUNCHER-MISSILE SYSTEM WITH AND WITHOUT AVI, FLIGHT TEST RESULTS

As justified in Section 4.8, the pitch and yaw vibrations of the launcher-missile system without the AVI will be approximately equal to those obtained when the AVI was locked with 100 psig pressure. In order to estimate the vibration isolation performance of the AVI in the pitch and yaw vibrations during the flight test, the pitch and yaw vibration levels are taken to be equal to those obtained when the AVI was locked with 100 spig pressure. The comparison of composite rms pitch and yaw accelerations with and without the AVI during hovering and 60 knot level flight in the flight test is shown in Table 23, it is seen that the AVI significantly reduced the pitch and yaw vibrations of the launcher-missile system during the flight test. The percentage of pitch and yaw vibration siolation is over 45 percent to as high as 75 percent. Since the pitch and yaw dynamic moment loads the launcher-missile system exerting on the helicopter stub-wing can be considered to be proportional to the composite rms values of the pitch and yaw accelerations, respectively. Thus the AVI also reduces the dynamic pitch and yaw moment loads the launcher-missile system exerting on the stub-wing by the same percentages as vibration isolation.

TABLE 4-23 . COMPARISON OF COMPOSITE RMS ACCELERATIONS WITH AND WITHOUT AVI, PITCH AND YAW VIBRATIONS, FLIGHT TEST

VIBRATION	HOVERING			60 KNOT LEVEL FLIGHT		
	COMPOSITE RMS ACCELERATION IN Rad/Sec^2		PERCENTAGE OF ISOLATION PERFORMANCE	COMPOSITE RMS ACCELERATION IN Rad/Sec^2		PERCENTAGE OF ISOLATION PERFORMANCE
	WITH AVI (A)	WITHOUT AVI ESTIMATED (B)	100(1-A/B)	WITH AVI (C)	WITHOUT AVI ESTIMATED (D)	100 (1-C/D)
PITCH	1.407	3.19	55.9	1.503	2.77	45.7
YAW	0.344	1.35	74.5	0.503	1.387	63.7

NOTE: Composite rms values covering a frequency range 0.6-50 Hertz were obtained with a 0.2 Hertz filter.

4.12 EXCITATION AND RESPONSE RMS ACCELERATION AND DISPLACEMENT DATA, LABORATORY RANDOM TESTS

Composite-root-mean-square values in both acceleration and displacement units of the excitations and responses of the AVI-launcher-missile system were computed from the power spectral density plots of the excitations and responses. The results are shown in Tables 4-24 through 4-29, with Tables 4-24 and 4-25 for vertical random tests, Tables 4-26 and 4-27 for transverse random tests, and Tables 4-28 and 4-29 for longitudinal random tests. The rms value of the spectrum is the square root of the area under the power spectral density plot, and is also the root-mean-square value of the vibration time history from which the psd plot is obtained. Thus the composite rms value is a meaningful quantity to measure the level of a random vibration covering a wide range of frequencies and a definite length of time. For each of the three axes of the laboratory random vibration tests, the rms values in acceleration unit are given in one table, and those in displacement unit are given in another table. It should be noted that the rms value in displacement unit is not proportional to the rms value in acceleration unit in general. Data in these tables verify this fact. Since the psd plot in displacement unit was obtained from the corresponding one in acceleration unit, the accuracy of the rms values in displacement unit will be less than that in acceleration unit. Thus care should be exercised in the application of the rms values in displacement unit.

TABLE 4-24. RESULTS OF COMPOSITE GRMS ACCELERATION, VERTICAL RANDOM TESTS, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 1 - 250 HERTZ

EXCITATION OR RESPONSE	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
Vertical Excitation	0.42	0.42	0.58	0.60	0.61	0.59	0.42	0.63
AVI-Lower-Plate-Center Vertical Response	0.053	0.79	0.084	1.12	0.29	0.189	0.43*	0.66*
Missile-Bottom-Center Vertical Response	0.164	0.79	0.177	1.03	0.29	0.22	0.74	1.65
Launcher-Front-End Vertical Response	0.093	1.24	0.19	1.71	0.45	0.34	1.02	2.17
Launcher-Rear-End Vertical Response	0.118	0.96	0.172	1.35	0.36	0.29	1.03	2.01

* These measurements were made at the center of the launcher left side.

TABLE 4-25. RESULTS OF COMPOSITE RMS DISPLACEMENT (INCH), VERTICAL RANDOM TESTS, OBTAINED WITH 0.2 HZ FILTER, FREQUENCY RANGE 0.5 - 50 HERTZ

EXCITATION OR RESPONSE	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
VERTICAL EXCITATION	0.038	0.041	0.063	0.095	0.136	0.075	0.041	0.051
AVI-LOWER-PLATE-CENTER VERTICAL RESPONSE	0.045	0.065	0.063	0.170	0.103	0.077	0.042 *	0.058 *
MISSILE-BOTTOM-CENTER VERTICAL RESPONSE	0.037	0.071	0.051	0.193	0.118	0.062	0.042	0.294
LAUNCHER-FRONT-END VERTICAL RESPONSE	0.178	0.157	0.169	0.42	0.120	0.117	0.080	0.68
LAUNCHER-REAR-END VERTICAL RESPONSE	0.139	0.065	0.133	0.138	0.062	0.074	0.041	0.38

* These measurements were made at the center of the launcher left side.

TABLE 4-26. RESULTS OF COMPOSITE GRMS ACCELERATION, TRANSVERSE RANDOM TESTS, OBTAINED WITH 0.2 HZ FILTER, FREQUENCY RANGE 1 - 250 HERTZ

EXCITATION OR RESPONSE	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
TRANSVERSE EXCITATION	0.49	0.47	0.66	0.68	0.65	0.68	0.76	0.74
AVI-LOWER-PLATE-CENTER TRANSVERSE RESPONSE	0.41	0.49	0.46	0.60	0.42	0.40	0.51	0.60
MISSILE-BOTTOM-CENTER TRANSVERSE RESPONSE	0.25	0.39	0.30	0.40	0.29	0.26	0.34	0.41
LAUNCHER-FRONT-END TRANSVERSE RESPONSE	0.33	0.67	0.38	0.80	0.36	0.36	0.40	0.72
LAUNCHER-REAR-END TRANSVERSE RESPONSE	0.38	0.50	0.41	0.57	0.38	0.38	0.39	0.40

TABLE 4-27. RESULTS OF COMPOSITE RMS DISPLACEMENT (INCH), TRANSVERSE RANDOM TESTS, OBTAINED WITH 0.5 HZ FILER, FREQUENCY RANGE 0.6 - 50 HERTZ

EXCITATION OR RESPONSE	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
TRANSVERSE EXCITATION	0.080	0.103	0.122	0.109	0.114	0.170	0.105	0.278
AVI-LOWER-PLATE-CENTER TRANSVERSE RESPONSE	0.058	0.061	0.098	0.083	0.096	0.096	0.092	0.097
MISSILE-BOTTOM-CENTER TRANSVERSE RESPONSE	0.067	0.086	0.099	0.126	0.106	0.100	0.092	0.130
LAUNCHER-FRONT-END TRANSVERSE RESPONSE	0.057	0.060	0.103	0.098	0.096	0.106	0.108	0.123
LAUNCHER-REAR-END TRANSVERSE RESPONSE	0.051	0.072	0.086	0.098	0.087	0.090	0.088	0.131

TABLE 4-28. RESULTS OF COMPOSITE GRMS ACCELERATION, LONGITUDINAL RANDOM TESTS, OBTAINED WITH 0.2 HZ FILER, FREQUENCY RANGE 1 - 250 HERTZ

EXCITATION OR RESPONSE	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
LONGITUDINAL EXCITATION	0.41	0.40	0.55	0.54	0.54	0.55	0.56	0.55
AVI-LOWER-PLATE-CENTER LONGITUDINAL RESPONSE	0.082	0.54	0.149	0.73	0.102	0.108	0.27	0.80
MISSILE-BOTTOM-CENTER LONGITUDINAL RESPONSE	0.057	0.37	0.112	0.38	0.081	0.082	0.211	0.35
LAUNCHER-FRONT-END VERTICAL RESPONSE	0.136	1.25	0.192	1.38	0.224	0.232	0.62	1.40
LAUNCHER-REAR-END VERTICAL RESPONSE	0.093	1.02	0.115	1.01	0.120	0.128	0.56	1.12

TABLE 4-29. RESULTS OF COMPOSITE RMS DISPLACEMENT (INGH), LONGITUDINAL RANDOM TESTS, OBTAINED WITH 0.2 HZ FILER, FREQUENCY RANGE 0.6 - 50 HERTZ

EXCITATION OR RESPONSE	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
LONGITUDINAL EXCITATION	0.067	0.066	0.091	0.092	0.099	0.091	0.094	0.096
AVI-LOWER-PLATE-CENTER LONGITUDINAL RESPONSE	0.081	0.068	0.117	0.087	0.113	0.108	0.124	0.092
MISSILE-BOTTOM-CENTER LONGITUDINAL RESPONSE	0.083	0.078	0.105	0.109	0.104	0.099	0.121	0.139
LAUNCHER-FRONT-END VERTICAL RESPONSE	0.148	1.09 *	0.098	1.89	0.061	0.058	0.134	
LAUNCHER-REAR-END VERTICAL RESPONSE	0.097	0.44 *	0.115	0.42	0.093	0.085	0.117	

4.13 COMPOSITE ROOT-MEAN-SQUARE VALUES OF VIBRATIONS OF AVI-LAUNCHER-MISSILE SYSTEM DURING HELICOPTER FLIGHT TEST, LINEAR MEASUREMENTS

Vibration root-mean-square values of the AVI-launcher-missile system during the helicopter flight test were obtained in both acceleration and displacement units for all linear measurements. The results are shown in Tables 4-30 through 4-35, with Tables 4-30 and 4-31 for AVI unlocked condition, Tables 4-32 and 4-33 for AVI 5 psig locked condition, and Tables 4-34 and 4-35 for AVI 100 psig locked condition. The results include all nine measurements and different flight conditions. Since 5 psig pressure is insufficient to move the AVI pneumatic locking system, the results of AVI 5 psig locked can be treated as AVI unlocked. When the AVI is locked with 100 psig pressure the vibrations of the launcher-missile system will be similar to those without the AVI.

TABLE 4-30. RESULTS OF RESPONSE GRMS ACCELERATION, FLIGHT TEST, AVI UNLOCKED, OBTAINED WITH 0.2 HZ FILTER, FREQUENCY RANGE 1-250 HERTZ

RESPONSE LOCATION AND AXIS	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
LAUNCHER-FRONT-END, TRANSVERSE		0.050	0.083	0.068	
LAUNCHER-FRONT-END, VERTICAL		0.159	0.241	0.160	
LAUNCHER-REAR-END, TRANSVERSE		0.062	0.085	0.066	
LAUNCHER-REAR-END, VERTICAL		0.150	0.234	0.154	
AVI-LOWER-PLATE-CENTER, TRANSVERSE		0.047	0.072	0.049	
AVI-LOWER-PLATE-CENTER, VERTICAL		0.037	0.065	0.043	
AVI-UPPER-PLATE-CENTER, LONGITUDINAL		0.169	0.225	0.214	
AVI-UPPER-PLATE-CENTER, TRANSVERSE		0.115	0.132	0.121	
AVI-UPPER-PLATE-CENTER, VERTICAL		0.178	0.389	0.294	

TABLE 4-31. RESULTS OF COMPOSITE RMS DISPLACEMENT RESPONSES, FLIGHT TEST, AVI UNLOCKED, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 0.6-50 HERTZ

RESPONSE LOCATION AND AXIS	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
LAUNCHER-FRONT-END, TRANSVERSE		0.061		0.083	0.067
LAUNCHER-FRONT-END, VERTICAL		0.201		0.187	0.228
LAUNCHER-REAR-END, TRANSVERSE		0.071		0.071	0.076
LAUNCHER-REAR-END, VERTICAL		0.186		0.182	0.222
AVI-LOWER-PLATE-CENTER, TRANSVERSE		0.056		0.052	0.061
AVI-LOWER-PLATE-CENTER, VERTICAL		0.046		0.045	0.060
AVI-UPPER-PLATE-CENTER, LONGITUDINAL		0.180		0.208	0.222
AVI-UPPER-PLATE-CENTER, TRANSVERSE		0.116		0.120	0.138
AVI-UPPER-PLATE-CENTER, VERTICAL		0.204		0.297	0.347

TABLE 4-32. RESULTS OF RESPONSE GRMS ACCELERATION, FLIGHT TEST, AVI 5 PSIG LOCKED, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 1-250 HERTZ

RESPONSE LOCATION AND AXIS	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
LAUNCHER-FRONT-END, TRANSVERSE	0.186	0.170		0.197	
LAUNCHER-FRONT-END, VERTICAL	0.420	0.421		0.429	
LAUNCHER-REAR-END, TRANSVERSE	0.263	0.259		0.247	
LAUNCHER-REAR-END, VERTICAL	0.347	0.354		0.393	
AVI-LOWER-PLATE-CENTER, TRANSVERSE	0.104	0.109		0.111	
AVI-LOWER-PLATE-CENTER, VERTICAL	0.173	0.189		0.259	
AVI-UPPER-PLATE-CENTER, LONGITUDINAL	0.121	0.142		0.203	
AVI-UPPER-PLATE-CENTER, TRANSVERSE	0.133	0.144		0.147	
AVI-UPPER-PLATE-CENTER, VERTICAL	0.236	0.262		0.289	

TABLE 4-33. RESULTS OF COMPOSITE RMS DISPLACEMENT RESPONSES, FLIGHT TEST 5 PSIG LOCKED, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 0.6 - 50 HERTZ

RESPONSE LOCATION AND AXIS	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
LAUNCHER-FRONT-END, TRANSVERSE		0.071	0.094	0.063	
LAUNCHER-FRONT-END, VERTICAL		0.201	0.346	0.292	
LAUNCHER-REAR-END, TRANSVERSE		0.064	0.099	0.093	
LAUNCHER-REAR-END, VERTICAL		0.187	0.312	0.366	
AVI-LOWER-PLATE-CENTER, TRANSVERSE		0.040	0.048	0.067	
AVI-LOWER-PLATE-CENTER, VERTICAL		0.116	0.206	0.244	
AVI-UPPER-PLATE-CENTER, LONGITUDINAL		0.110	0.141	0.069	
AVI-UPPER-PLATE-CENTER, TRANSVERSE		0.036	0.093	0.055	
AVI-UPPER-PLATE-CENTER, VERTICAL		0.092	0.177	0.212	

TABLE 4-34. RESULTS OF RESPONSE GRMS ACCELERATION, FLIGHT TEST, AVI 100 PSIG LOCKED, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 1-250 HERTZ

RESPONSE LOCATION AND AXIS	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
LAUNCHER-FRONT-END, TRANSVERSE		0.058		0.074	0.105
LAUNCHER-FRONT-END, VERTICAL		0.234		0.286	0.321
LAUNCHER-REAR-END, TRANSVERSE		0.055		0.133	0.109
LAUNCHER-REAR-END, VERTICAL		0.218		0.328	0.374
AVI-LOWER-PLATE-CENTER, TRANSVERSE		0.041		0.079	0.084
AVI-LOWER-PLATE-CENTER, VERTICAL		0.124		0.207	0.245
AVI-UPPER-PLATE-CENTER, LONGITUDINAL		0.080		0.112	0.150
AVI-UPPER-PLATE-CENTER, TRANSVERSE		0.029		0.078	0.062
AVI-UPPER-PLATE-CENTER, VERTICAL		0.105		0.185	0.216

TABLE 4-35. RESULTS OF COMPOSITE RMS DISPLACEMENT RESPONSES, FLIGHT TEST, AVI 100 PSIG LOCKED, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 0.6-50 HERTZ

RESPONSE LOCATION AND AXIS	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
LAUNCHER-FRONT-END, TRANSVERSE	0.093	0.053		0.037	
LAUNCHER-FRONT-END, VERTICAL	0.137	0.112		0.205	
LAUNCHER-REAR-END, TRANSVERSE	0.118	0.082		0.101	
LAUNCHER-REAR-END, VERTICAL	0.214	0.175		0.270	
AVI-LOWER-PLATE-CENTER, TRANSVERSE	0.065	0.034		0.050	
AVI-LOWER-PLATE-CENTER, VERTICAL	0.150	0.124		0.205	
AVI-UPPER-PLATE-CENTER, LONGITUDINAL	0.129	0.116		0.097	
AVI-UPPER-PLATE-CENTER, TRANSVERSE	0.072	0.036		0.056	
AVI-UPPER-PLATE-CENTER, VERTICAL	0.150	0.125		0.203	

4.14 PITCH AND YAW VIBRATIONS OF THE AVI-LAUNCHER-MISSILE SYSTEM DURING FLIGHT

Angular accelerometers were not available to measure the pitch and the yaw vibrations of the AVI-launcher-missile system during the flight test. However, pitch and yaw vibrations of the AVI-launcher-missile system were obtained from the linear accelerometer measurements. This was done by dividing the algebrai sum of two accelerometer signals along the same axis by the distance between these two accelerometers. Composite rms values of the pitch and the yaw vibrations of the AVI-launcher-missile system were also computed from the psd plots and the results are shown in Tables 4-36 and 4-37. It is seen that the composite rms value of the pitch vibrations of the AVI-launcher-missile system is slightly more than the yaw. These composite rms values covering a range of frequencies 0.6-50 Hertz were obtained with a 0.2 Hertz filter. Since the pitch and yaw vibrations were obtained indirectly from the linear accelerometer measurements, the data cannot be expected to be very accurate. However, the data at least provides an order of magnitudes of the pitch and yaw vibrations of the AVI-launcher-missile system during the flight test.

TABLE 4-36. RESULTS OF COMPOSITE RMS PITCH AND YAW ACCELERATIONS IN RADIAN PER SECOND SQUARED, FLIGHT TEST, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 1-250 HERTZ

DESCRIPTION	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
COMPOSITE RMS ACCELERATION, PITCH VIBRATION, AVI UNLOCKED		1.407	2.149	1.503	
COMPOSITE RMS ACCELERATION, PITCH VIBRATION, AVI 5 PSIG LOCKED		1.764		1.767	1.854
COMPOSITE RMS ACCELERATION, PITCH VIBRATION AVI 100 PSIG LOCKED	3.25	3.19		2.77	
COMPOSITE RMS ACCELERATION, YAW VIBRATION, AVI UNLOCKED		0.344	0.530	0.503	
COMPOSITE RMS ACCELERATION, YAW VIBRATION, AVI 5 PSIG LOCKED		0.400		0.592	0.475
COMPOSITE RMS ACCELERATION, YAW VIBRATION, AVI 100 PSIG LOCKED	1.600	1.350		1.387	

TABLE 4-37. RESULTS OF COMPOSITE RMS PITCH AND YAW DISPLACEMENTS IN RADIAN/DEGREE, FLIGHT TEST, OBTAINED WITH 0.2 HERTZ FILTER, FREQUENCY RANGE 0.6-50 HERTZ

DESCRIPTION	TAKE-OFF	HOVERING	30 KNOT LEVEL FLIGHT	60 KNOT LEVEL FLIGHT	LANDING
COMPOSITE RMS DISPLACEMENT, PITCH VIBRATION, AVI UNLOCKED		0.0046/0.264	0.0076/0.435	0.0059/0.338	
COMPOSITE RMS DISPLACEMENT, PITCH VIBRATION, AVI 5 PSIG LOCKED		0.0056/0.321		0.0061/0.350	0.0063/0.361
COMPOSITE RMS DISPLACEMENT, PITCH VIBRATION, AVI 100 PSIG LOCKED	0.0021/0.120	0.0012/0.0688		0.0017/0.0974	
COMPOSITE RMS DISPLACEMENT, YAW VIBRATION, AVI UNLOCKED		0.0017/0.0974	0.0025/0143	0.0014/0.0802	
COMPOSITE RMS DISPLACEMENT, YAW VIBRATION, AVI 5 PSIG LOCKED		0.0012/0.0688		0.0023/0.132	0.0021/0.120
COMPOSITE RMS DISPLACEMENT, YAW VIBRATION, AVI 100 PSIG LOCKED	0.0023/0.132	0.0018/0.103		0.0017/0.0974	

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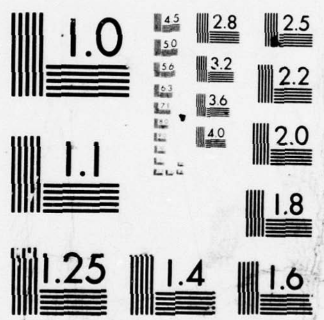
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4.15 RESPONSE PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES, SWEEP-SINE TEST RESULTS

The predominant response frequencies and the transmissibilities of base vibration transmitted to the launcher-missile system through the AVI were determined from the transfer function plots of the sweep-sine tests results. Tables 4-38 through 4-41 show the perdominant response frequencies and the transmissibilities of all vertical sweep-sine tests. Tables 4-42 through 4-45 show the predominant response frequencies and the transmissibilities of all transverse sweep-sine tests. Tables 4-46, through 4-49 show the predominant response frequencies and the transmissibilities of all longitudinal sweep-sine tests. The predominant frequencies are the peak response frequencies of the transfer function plots. Some of the predominant frequencies may be the natural frequencies of the AVI-launcher-missile system, and some may not be. In addition to the predominant frequencies and the corresponding transmissibilities at these frequencies, the transmissibilities at 11, 22, 33, and 44 Hertz are also given in these tables. Because of the limitation of the test and data reduction equipment, many of the response data show much fluctuation at low frequencies below 3 Hertz. Thus the system natural frequencies in this low frequency range cannot be determined accurately from the sweep-sine test results. These data of the response/excitation transfer functions obtained from the sweep-sine tests show the complexity of the dynamic behavior of the AVI-launcher-missile system under different operating conditions. From these data one natural frequency of one of the longitudinal-pitch modes of the AVI-launcher-missile system can be determined to be 3.8 Hertz, and the vertical natural frequency of the AVI-launcher-missile system to be 2.4 Hertz when the AVI is in the fully floating condition.

TABLE 4-38. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF AVI-LOWER-PLATE-CENTER VERTICAL RESPONSE TO VERTICAL EXCITATION, SWEEP-SINE TESTS

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	2.3/1.45		77/0.125	118/0.11	155/0.11	0.1	0.028	0.022	0.017
1A	2.4/1.8		76/0.29	120/0.36	155/0.31	0.21	0.18	0.18	0.18
2	12/1.9		90/1.16		165/1.55	1.7	0.72	0.62	0.42
3	8.3/1.4	15/0.45	82/0.44		155/0.54	0.8	0.15	0.24	0.26
4	3.4/1.15	56/0.13	72/0.15	90/0.19	112/0.2	0.14	0.047	0.034	0.032
5	12.2/2.0		90/0.75	130/0.64	160/1.15	1.7	0.71	0.55	0.35
6	7/1.4		79/0.5	130/0.8	153/0.9	0.57	0.19	0.20	0.19
7	8.3/1.5		84/0.52	130/0.22	160/1.1	0.87	0.30	0.30	0.25
8	5.7/1.25		88/0.33	133/0.31	160/0.49	0.35	0.11	0.11	0.12
9	6.5/1.32		84/0.39		163/0.78	0.48	0.15	0.16	0.15
10	2.5/1.12		98/1.2			1	1	1	1
10A	2.5/1.15		99/1.15			1	1	1	1

TABLE 4-39. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF MISSILE-BOTTOM-CENTER VERTICAL RESPONSE TO VERTICAL EXCITATION, SWEEP-SINE TESTS

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	2.3/1.35	79/0.032		120/0.078	160/0.11	0.1	0.03	0.023	0.019
1A	2.4/1.8	79/0.19		122/0.033	160/0.34	0.20	0.19	0.19	0.18
2	12/1.8	88/0.22		134/0.19	163/1.15	1.6	0.7	0.52	0.33
3	8.4/1.75	80/0.23		131/0.24	156/0.65	0.74	0.32	0.18	0.17
4	3/1.2	78/0.058		114/0.083	156/0.38	0.14	0.049	0.038	0.041
5	12.1/1.9	88/0.27		130/0.62	160/0.71	1.65	0.64	0.45	0.27
6	7/1.35	78/0.21		130/0.77	152/0.69	0.56	0.16	0.16	0.14
7	8.4/1.5	81/0.14		130/0.21	160/1	0.87	0.27	0.23	0.19
8	5.6/1.28	72/0.11		130/0.23	160/0.64	0.34	0.11	0.1	0.09
9	6.4/1.3	77/0.12		132/0.23	165/0.85	0.47	0.14	0.13	0.11
10	2.5/1.2	25/1.2	41/1.4	132/1.8	164/3.6	1	0.6	0.7	1.2
10A	2.5/1.2	25/1.1	41/1.8	132/1.8	164/3.6	1	0.6	0.7	1.1

TABLE 4-40. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF LAUNCHER-FRONT-END VERTICAL RESPONSE TO VERTICAL EXCITATION, SWEEP-SINE TESTS

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	2.3/1.7		79/0.34	132/0.16	160/0.28	0.1	0.04	0.023	0.026
1A	2.4/2.2		78/0.71	133/0.31	160/0.89	0.25	0.22	0.23	0.22
2	12.5/2.1	25.5/1.12	45/0.75	102/1.25	164/2.2	1.9	0.8	0.6	0.7
3	8.4/2.3	27/1.08	81/1.41	131/0.78	160/1.45	0.94	0.28	0.82	0.75
4	3.5/1.55		78/0.58	135/0.56	160/0.88	0.19	0.047	0.028	0.028
5	12/2.45		91/0.73	130/0.9	165/1.5	2.0	0.79	0.47	0.22
6	7/1.4		80/0.57	130/1.1		0.63	0.19	0.20	0.20
7	8.3/1.6		88/1.4	130/0.63	160/1.9	0.95	0.37	0.47	0.40
8	5.6/1.4		87/0.98	130/0.72	160/1.5	0.38	0.09	0.06	0.23
9	6.4/1.4		87/1.18	132/0.72	162/1.75	0.50	0.13	0.33	0.33
10	2.5/1.25	28/0.90	96/3.2		162/3.4	0.98	0.35	0.4	0.5
10A	2.4/1.26	27/0.94	103/3.8		165/3.5	0.98	0.3	0.4	0.5

TABLE 4-41. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF LAUNCHER-REAR-END VERTICAL RESPONSE TO VERTICAL EXCITATION, SWEEP-SINE TESTS

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	2.3/1.3		79/0.094	120/0.15	160/0.11	0.13	0.04	0.026	0.020
1A	2.4/1.6		79/0.22	122/0.4	160/0.34	0.21	0.18	0.18	0.17
2	11.6/1.55	37/0.58	97/1.5	110/0.69	140/1.20	1.22	0.5	0.53	0.25
3	4.3/1.20	7/0.86	25/0.52	81/0.94	113/0.35	0.35	0.30	0.30	0.27
4	3/1.1	25/0.14		78/0.22	113/0.25	0.11	0.041	0.05	0.045
5	12/1.6	25.5/0.61	41/0.39	90/0.27	130/0.25	1.16	0.53	0.47	0.34
6	7/1.24	25.5/0.16	130/0.31	148/1.1	175/1.1	0.46	0.15	0.14	0.12
7	8.2/1.28	25/0.33	45/0.29	84/0.72	105/0.94	0.72	0.24	0.09	0.28
8	5.4/1.1	20/0.127	81/0.39	109/0.67	163/1.15	0.28	0.10	0.1	0.1
9	6.2/1.12	81/0.51	110/0.77	140/0.84	163/1.15	0.38	0.135	0.15	0.06
10	2.5/1.11	23/1.3	105/2.4	142/3.4	168/3.7	1.02	1.1	0.6	0.6
10A	2.5/1.1	23/1.4	103/2.7	142/3.6	166/3.8	1.01	1.2	0.64	0.6

TABLE 4-42. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF AVI-LOWER-PLATE-CENTER TRANSVERSE RESPONSE TO TRANSVERSE EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1		14.5/1.42	17.5/1.38	22/1.15	65/0.87	1.01	1.1	0.4	0.1
1A		14.5/1.43	17.5/1.38	22/1.14	65/0.87	1.01	1.1	0.38	0.1
2	5.9/1.13	14.5/1.04		33/1.45	60/0.48	0.98	0.87	1.45	0.64
2A	22.5/1.32	43/0.41	99/1.65	125/2.3	175/2.4	0.83	0.81	0.24	0.41
3	24/1.26	44/0.69	91/1.35	130/1.7	185/1.3	0.79	0.86	0.48	0.69
4	22/2.3	66/0.84	112/0.33	135/0.2	170/0.074	1.	2.3	0.55	0.15
5	18/1.48	22/2.2	66/0.67	104/0.24	170/0.09	0.94	2.2	0.49	0.1
6	7.8/1.17	26/0.94	45/1.39	79/0.63	122/2.2	0.81	0.75	0.85	1.39
7	15/1.25	17.5/1.55	20/2.2	60/0.81		0.93	2.	0.48	0.1
8	17/1.77	23/1.38	27/1.39	71/0.56	105/0.28	0.95	1.25	0.9	0.36

TABLE 4-43. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF MISSILE-BOTTOM-CENTER TRANSVERSE RESPONSE TO TRANSVERSE EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	3.8/1.14	17/0.6	24/1.32	64/0.48		0.47	1	0.4	0.25
1A	1.9/1.9	3.8/1.1	17/0.63	23/1.15	64/0.48	0.45	0.85	0.42	0.28
2	6.4/2.65	8.5/2.3	16/1.56	33/2.7		2.1	1.13	2.7	2.1
2A	6/2.9	11/2	16/1.6	23/2	104/1.65	2	1.1	0.71	0.47
3	24/1.45	104/1.35	125/1.15	140/1.11	180/2	0.65	0.86	0.7	0.54
4	22/0.99	30/0.79	62/0.53	135/0.37	180/0.59	0.39	1	0.561	0.35
5	22/1.12	30/0.78	65/0.46	140/0.47	186/0.65	0.39	1.12	0.53	0.37
6	9-14/2.6	28/1.18	49/1.6	92/1.12	130/1.55	2.6	1	1.1	1.52
7	21/1.4	33/0.6	56/0.66	63/0.57	112/1.19	0.46	2.12	0.6	0.39
8	23/1.14	28/1.01	40/0.42	89/0.27	130/0.4	0.41	1	0.8	0.35

TABLE 4-44. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF LAUNCHER-FRONT-END TRANSVERSE RESPONSE TO TRANSVERSE EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	3.5/1.28	15/1.05	18/1.12	23/0.99	67/0.4	0.61	0.95	0.34	0.2
1A	3.5/1.2	15/1.08	18/1.1	23/0.97	68/0.47	0.55	0.7	0.4	0.23
2	5.9/1.19	15/1.06	38/4.1	61/1.41	75/1.61	0.97	0.85	2	1.9
2A	14/1.02	24/2.35	105/3.3	150/4.7	175/3.7	0.9	0.77	0.53	0.44
3	25/2.05	110/3	135/4.4	150/4	190/2.4	0.75	0.9	0.75	0.48
4	16/1.5	23/2.5	40/0.43	69/0.43	145/0.79	1.08	2	0.5	0.25
5	18/1.65	23/2.12	40/0.43	69/0.39	146/0.67	0.68	1.8	0.54	0.2
6	8/1.35	24/1.55	55/3.3	130/3.9	130/4	0.91	0.91	1.08	2.6
7		18/1.65	23/1.8			0.67	1.7	0.58	0.2
8	17.5/1.48	23/1.25	28/1.4	69/2.1	130/0.83	0.7	0.9	1.09	0.62

TABLE 4-45. PREDOMINANT FREQUENCIES OF TRANSMISSIBILITIES OF LAUNCHER-REAR-END TRANSVERSE RESPONSE TO TRANSVERSE EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	5.5/1.05	14.5/1.3	22/1.19	24/1.03	67/0.5	0.99	1	0.42	0.21
1A	5.5/1.09	14.5/1.25	17/1.23	21.5/1.35	67/0.55	1	1	0.45	0.25
2	5.9/1.18	14.5/0.96	34/1.95	38.5/1.5		0.88	0.7	1.8	1.28
2A	5.9/1.24	13.5/0.97	23/1.9	100/3.7	144/4.5	0.83	0.75	0.15	0.25
3		25/1.25	106/3.1	130/2.9	145/2.6	0.6	0.65	0.35	0.53
4	12/0.75	19/1.11	22.5/1.95	67/0.56	144/0.57	0.7	1	0.68	0.33
5	7.8/1.04	21.5/2.4	68/0.46	116/0.23	142/0.48	0.95	2.1	0.62	0.31
6	8/1.4	25.5/1.35	45/1.4	82/1.2	152/2.7	0.84	0.42	0.85	1.4
7	5.5/1.15	20/2.45	32/0.73			0.92	2	0.62	0.3
8	17/1.75	22.5/1.3	27/1.3	72/0.73	125/0.39	1	1.25	0.84	0.4

TABLE 4-46. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF AVI-LOWER-PLATE-CENTER LONGITUDINAL RESPONSE TO LONGITUDINAL EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	3.8/2.45					0.44	0.18	0.09	0.05
2		24/2.0		35/2.2	40/2.5	1.	1.65	1.3	2.1
3		24/2.0	30/2.2	35/2.3	41/2.4	1.	1.9	1.25	2.
4		24/1.45	27.5/2.15	32/1.25	40/2.4	1.	1.35	1.05	2.2
5		25/2.1	31/1.35	39/2.3	46/3.1	1.	1.30	0.91	2.6
6	16/1.3	23/1.5	26/1.6	37.5/2.0	45/2.7	1.05	1.30	1.3	2.4
7	23.5/1.65	27/1.3	33/1.6	38/1.9	47/2.4	1.05	1.30	1.65	2.3
8		23.5/1.45	33/1.4	38/1.85	43/2.1	1.05	1.38	1.3	2.1
9	22/1.5	26.8/1.25	34/1.35	34/1.35	42/1.61	1.03	1.50	1.26	1.6
10	22/1.56	26.8/1.25	34/1.35	34/1.37	40/1.50	1.03	1.56	1.26	1.48
11	13.5/1.35	21/1.19			41/4.64	1.05	1.04	1.72	4.1
11B	14/1.38	25.5/1.45	27/1.48		41/5.0	1.05	1.20	1.71	5.0
12		13.5/2.1				1.10	0.11	0.072	0.053
12A	4/2.85					0.415	0.105	0.069	0.047

TABLE 4-47. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF MISSILE-BOTTOM-CENTER LONGITUDINAL RESPONSE TO LONGITUDINAL EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	4/1.65					0.31	0.125	0.07	0.044
2	8/1.35	10.9/1.38	18.0/1.19	24/2.20	44/1.45	1.30	1.65	0.41	1.45
3	8.5/1.40	10.9/1.41	18.5/1.20	24.5/2.27	42.5/1.39	1.30	1.65	0.41	1.25
4	9.4/1.33	18.1/1.23	25/1.25	28/2.55	42/1.65	1.05	1.08	0.97	1.3
5	9.1/1.48	10.9/1.08	17.8/1.55	27/2.45	41/1.42	1.0	1.01	0.7	1.25
6	8.7/1.25	16.5/1.22	23/1.25	26/1.60	43/1.75	0.80	1.10	0.89	1.5
7	8.3/1.22	15/0.98	24/1.65	38/1.24	43.5/1.60	0.83	1.09	1.15	1.4
8	7.3/1.19	24/1.38	36/0.99	40.5/1.20	43.5/1.37	0.90	0.94	0.78	1.22
9	5.1/1.07	23.5/1.30	28/1.11	37/0.92	43/1.09	0.82	0.99	0.81	1.07
10	5.0/1.07	22.5/1.15	27/1.01	36/0.92	41/1.01	0.80	1.04	0.89	1.
11	13.3/4.0		20/0.70		40/3.4	1.50	0.36	1.22	2.7
11B	14/4.2		26/1.03		42/3.60	1.50	0.60	1.	2.
12	2.6/1.22	13.4/1.55				0.67	0.07	0.047	0.036
12A	4.0/1.83					0.25	0.07	0.044	0.034

TABLE 4-48. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF LAUNCHER-FRONT-END VERTICAL RESPONSE TO LONGITUDINAL EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	3.8/2.35					0.41	0.15	0.058	
2	8.9/0.54	10.6/0.89	15/1.06	19/2.2	32/2.85	0.7	0.8	2.7	3.4
3	8.8/0.7	10.6/0.80	14.5/1.10	19/1.95	33/2.85	0.7	0.85	2.8	3.5
4	10.4/1.08	15.6/1.18	18/4.1	33/4.15	48/6.0	0.64	0.8	4.15	4.8
5	8/0.8	10.7/0.91	18/4.8	33/4.4	46/6.2	0.45	0.55	4.4	5.5
6	8.8/0.65	9.7/0.66	16.2/1.55	27/4.4	44/6.2	0.52	0.80	4.4	6.0
7	8.8/0.64	15.5/1.3	17.5/1.32	30/4.3	45/6.3	0.53	1.0	3.5	6.0
8	8.7/0.65	17.5/1.23	25/3.3	30/4.3	45/6.0	0.75	1.1	3.8	6.1
9	9.6/0.79	12.8/1	20/1.25	33/3.9	44/5.1	0.8	1.3	3.8	5.1
10	10.4/0.86	13/0.99	23/3.0	33/4	44/4.8	0.8	1.2	3.8	4.8
11		14/6.0	20/2.4		41/4.7	1.1	1.55	2.0	4.1
11B		15/7.1	27/2.2		44/5.1	1.05	2.2	1.75	5.1
12	3/1.7	13.5/1.7				1.1	0.1	0.068	0.05
12A	3.7/2.5					0.33	0.085	0.034	0.004

TABLE 4-49. PREDOMINANT FREQUENCIES AND TRANSMISSIBILITIES OF LAUNCHER-REAR-END VERTICAL RESPONSE TO LONGITUDINAL EXCITATION, SWEEP-SINE TEST

TEST IDENT.	PREDOMINANT FREQUENCY (HERTZ) AND TRANSMISSIBILITY					TRANSMISSIBILITY AT			
	I	II	III	IV	V	11 HZ	22 HZ	33 HZ	44 HZ
1	3.7/1.7					0.32	0.086	0.034	0.014
2	9.1/0.43	11.3/0.78	19.2/2.0	32/2.6	43/3.0	0.64	0.85	2.4	2.6
3	8.9/0.45	11.6/0.74	20/1.75	32/2.5	42/2.8	0.64	1.05	2.3	2.5
4	10/0.64	15.5/0.74	23/1.2	29/3.9	44/4.5	0.35	0.9	3.2	3.1
5	9.7/0.53	15/0.57	21/1.04	27.5/3.7	45/4.7	0.40	0.55	4.15	5.8
6	8.9/0.57	14/0.59	25/2.6	29/3.5	44/4.6	0.41	1.03	3.0	4.5
7	9/0.57	14/0.62	25/2.4	29/3.3	45/4.5	0.41	1.1	2.6	4.3
8	8.8/0.55	14.5/0.61	25/2.5	29/3.1	44/4.1	0.55	0.9	2.5	4.1
9	8.5/0.85	13.5/0.76	23/2.1	29/2.6	44/3.2	0.7	1.	2.4	3.2
10	8.8/0.88	12.5/0.75	23/2.1	30/2.4	43/2.9	0.7	1.	2.4	2.7
11		13.9/4.1	21/2.9		41/3.55	0.55	2.6	1.6	3.0
11B		14.5/4.4		28/2.7	42/4.6	0.60	0.70	2.2	1.
12	3/1.2	13.4/1.55				0.82	0.068	0.044	0.03
12A	4/2.4					0.27	0.063	0.007	

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the results of the helicopter flight test, the laboratory longitudinal vibration test, the transverse vibration test, and the vertical vibration test of the flight demonstration model of the airspring vibration isolator, the following conclusions can be made.

(a) Laboratory vertical vibration tests, including sweep-sine and random tests, were performed with and without the AVI. The results show that vibration levels of the launcher-missile system with the AVI is significantly less than without the AVI. For random tests, the percentage of isolation was found to be over 99 percent for power spectral densities at critical frequencies 11 and 22 Hertz, and 78 percent to 91 percent for composite root-mean-square values in acceleration unit covering a frequency range from 1 to 250 Hertz. For sweep-sine tests, the percentage of isolation was found to be 89 percent to 97 percent for critical frequencies 11, 22, 33, and 44 Hertz.

(b) In laboratory longitudinal and transverse vibration tests, the launcher-missile system without the AVI was not tested. The composite root-mean-square values in acceleration units of the launcher-missile system without the AVI were estimated. The percentage of vibration isolation for longitudinal random excitations of the AVI was found to be 54 percent to 86 percent. Because of the Government furnished longitudinal isolator mount leaking during the transverse vibration tests, the percentage of isolation for transverse excitations cannot be accurately determined.

(c) During the helicopter flight test, the launcher-missile system without the AVI was not flown. Vibration levels in acceleration unit of the launcher-missile system without the AVI were estimated from the AVI flight test data as well as previous flight tests data. The percentage of vibration isolation of the AVI at the launcher front and rear ends in the vertical and transverse directions was found to be 47 percent to 75 percent for composite root-mean-square values in acceleration unit covering a range of frequencies from 1 to 250 Hertz.

(d) The pitch and yaw vibrations of the launcher-missile system during the helicopter flight test were also determined. Comparison of pitch and yaw vibrations of the launcher-missile system with and without the AVI was performed. It is found that the percentage of isolation of the AVI is 46 percent to 56 percent for pitch, and 64 percent to 75 percent for yaw vibration.

(e) It was found that the AVI can also reduce the dynamic loads exerted by the launcher-missile system on the helicopter stub-wing, thereby extending service life and reducing maintenance cost. The percentage of reduction of the dynamic loads was estimated to be 45 percent to 75 percent along the vertical and transverse axes, 46 percent to 56 percent for pitch moment, and 64 percent to 75 percent for yaw movement.

(f) The current seeker isolation package employed on the Hellfire missile is also designed to isolate the rotor-induced vibrations as the AVI. Therefore the AVI and the current seeker isolation package essentially perform the same function. However, the seeker isolation package is an expensive expendable item. The AVI being a resuable package will afford a substantial cost savings with the added flexibility of being adaptable to a variety of payloads.

(g) Although the AVI does significantly reduce the composite rms value of the vibration of the launcher-missile system in acceleration unit it does not significantly reduce composite rms value of the vibration levels in displacement unit. This is due to the low frequency vibrations which contribute insignificantly to the composite rms acceleration but contribute significantly to the composite rms displacement. It is believed that further development can improve the AVI isolation performance in this respect.

5.2 RECOMMENDATIONS

The design, manufacture, laboratory vibration tests, and the flight test of the helicopter flight demonstration model of the AVI were performed with limited funding and manpower. The development and investigation is not exhaused. Since results of the laboratory vibration tests and helicopter flight test as presented in this report show that the vibration isolation of the AVI is very good, the following development, improvement, and tests of the AVI are recommended:

(a) To investigate the vibration isolation performance of the AVI, the best way is to perform helicopter flight tests of the same launcher-missile system with and without the AVI in identical flight conditions and compare the responses at the same locations of the launcher-missile system. Thus it is recommended that a helicopter flight tests of the same launcher-missile system be performed without the AVI and with a flight profile identical to that for the AVI flight test.

(b) Improved servo-level pneumatic isolator mounts should be developed and an improved flight model of the AVI should be designed and manufactured.

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